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# Long Wavelength Video-based Event Detection, Preliminary Results from the CVNX and VS1 Test Series, ex-USS *Shadwell*, April 7-25, 2003

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**14. ABSTRACT**
This report documents results from long wavelength-response, or nightvision video detection (LWVD) of fire, smoke, and hot objects obtained during the CVNX and VS1 Test Series. The cameras demonstrated thermal imaging capabilities and an enhanced sensitivity to flaming fires and other hot objects when compared to co-located regular video cameras. Video event detection with long wavelength cameras is discussed and compared with the results of video event detection systems using regular cameras. For quantitative comparison to the commercial video-based fire detection systems, a simple luminosity-based algorithm was developed and used to evaluate camera/filter combinations for fire, smoke, and nuisance (false) event detection and response times. The LWVD system provides higher detection sensitivity but also more false alarms when compared to regular video detection systems. The thermal imaging capabilities of the LWVD system are evaluated based on comparison with temperature measurements of a fire-heated bulkhead and a laboratory blackbody emitter. Good agreement is obtained for hot objects at temperatures above 400°C.

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## ACRONYMS USED

| | |
|---|---|
| ACH | Air Changes per Hour |
| ADC | Advanced Damage Countermeasures Program |
| AVI | Audio Video Interleaved |
| CCD | Charge Coupled Device |
| CVN21 | Future Aircraft Carrier, CVN 21. Formerly known as CVNX |
| CVNX | Carrier Vehicle, Nuclear Experimental" |
| CVNX | CVN21 Fire Threat to Ordnance Test Series 2 |
| FNC | Future Naval Capability, sponsored by ONR |
| FOV | Field Of View |
| FPS | Frames Per Second |
| FR | Frame Number, indicates location Fore to Aft onboard a ship (ex. FR27) |
| GUI | Graphical User Interface |
| JPEG | Joint Photographic Experts Group. Also a standard for still digital images |
| L | Luminosity |
| LOS | Line Of Sight |
| LP | Longpass, passes wavelengths greater than a cutoff wavelength |
| LWVD | Long Wavelength-response Video Detection |
| MJPEG | motion JPEG standard for digital video |
| MV | Machine Vision |
| NIR | Near InfraRed |
| NRL | Naval Research Laboratory |
| NV | Not Ventilated |
| OH | OverHead |
| ONR | Office of Naval Research |
| PD | PhotoDiode |
| RGB | Red, Green, Blue |
| SBVS | Spectral-Based Volume Sensor |
| SFA | Smoke and Fire Alert, a VIDS product of Fastcom Technology, S.A. |
| SigniFire | a VIDS product of AxonX LLC |
| TC | ThermoCouple |
| VCR | Video Cassette Recorder |
| VHS | Video Home System, a magnetic media format for recording video with a VCR |
| VID(S) | Video Image Detection (System) |
| VS | Volume Sensor |
| VS1 | Volume Sensor Test Series 1 |
| VSD-8 | Visual Smoke Detection System, a VIDS product of Fire Sentry Corp. |

# LONG WAVELENGTH VIDEO-BASED EVENT DETECTION, PRELIMINARY RESULTS FROM THE CVNX AND VS1 TEST SERIES, EX-USS *SHADWELL*, APRIL 7-25, 2003

## INTRODUCTION

This report details the initial results of long wavelength video collection and analysis done as part of the Spectral-Based Volume Sensor (SBVS) Component of the Advanced Damage Countermeasures (ADC) Program during the CVN21 Fire Threat to Ordnance Test Series 2 (CVNX) and the Volume Sensor Test Series 1 (VS1). These test series were conducted aboard the ex-USS *SHADWELL*, the U.S. Naval Research Laboratory's (NRL) full-scale fire research facility, in Mobile, Alabama [1] during the period of April 7 – 25, 2003 [2-5].

The Volume Sensor concept is the simultaneous remote detection of flaming and smoldering fires and other surveillance / threat condition events within a ship space. This will be accomplished primarily by the use of machine vision (MV) / image analysis of live video streams from various compartments and areas of the ship. The development and refinement of the image analysis algorithms to be used is a major focus of the Volume Sensor (VS) Program. In order to improve the event detection / false alarm rejection characteristics of the video-based systems, several other sensing approaches or kinds of detection are also being explored, such as acoustic signatures and spectral-based volume sensing. Long wavelength-response video detection (LWVD), one facet of the latter, is the focus of this report. Another facet of the SBVS Component is the SBVS Testbed, which is composed of single- and multiple-element optical detectors that operate outside the visible spectrum for flame detection. The design, implementation, initial laboratory testing [6], and VS1 testing [5] of the SBVS Testbed have been documented previously.

The SBVS Component employs optical methods generally outside the visible portion of the electromagnetic spectrum to expand and enhance the remote sensing capability of the overall Volume Sensor. SBVS Components are intended to be used in conjunction with video-based image detection (VID) / MV, with all data sources available for fusion during algorithmic event detection. One approach being pursued within the SBVS Component is the use of long wavelength or nightvision[1] video cameras [6]. Nightvision video fire detection is an approach to access both spectral and spatial information using inexpensive equipment. The approach exploits the long wavelength response (to about 1 micron) of standard, i.e., inexpensive, CCD arrays[2] used in many video cameras (e.g., camcorders and surveillance cameras). This region is slightly to the red (700-1000 nm) of the ocular response (400-650 nm). There is more emission from hot objects in this spectral region than in the visible (<600 nm) [6]. The addition of a longpass (LP) filter transmiting light with wavelengths longer than a cutoff, typically in the range 700-900 nm, increases the contrast for flaming fire and hot objects, while suppressing the normal video images of the space. This approach can provide a modest level of thermal imaging.

The CVNX test series was primarily designed to evaluate the performance of existing Navy magazine detection systems and to evaluate VID technology against a limited set of source fires. The

[1] Nightvision often implies a phosphor screen for visualizing NIR images (700-1000nm) in the region CCD cameras respond. There are several "generations" of this kind of nightvision viewer, often designated Gen I through Gen III; the higher number corresponds to more amplification of the image. We are using the term nightvision to indicate the NIR (<1 μm) spectral region.

[2] For example see the specifications for the Sony CCD array ILX554B.

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VS1 test series consisted of relatively small fires, smoke sources, and nuisance sources with a larger variety than the CVNX test series [4]. The test sources were kept small in scale to challenge the ability of the video-based fire detection system [2,3] to resolve small flame / smoke sources. As an additional challenge to both the video-based systems and the SBVS Testbed, many of the sources were partially or completely obscured from the detector's field of view (FOV). Nuisance sources were selected to represent typical shipboard activities that might cause false alarm conditions. The FY02 studies of the video-based systems indicated the potential for false alarms from personnel working in the ship spaces causing variation in brightness and reflectivity [7]. The LWVD system described in this report is not as mature a system as the commercial VID systems (VIDS), nor are there any commercial LWVD systems currently available. In the VS program, nightvision cameras have not been previously included in shipboard or other ship-like compartment testing. The LWVD system still requires further algorithm development to properly detect events such as smoke and flame with acceptable nuisance rejection. Continued validation of source detection and nuisance rejection is also needed before the accuracy and speed of the LWVD can be assessed. This report documents the initial efforts towards this goal.

## EXPERIMENTAL SETUP AND PROCEDURES

The CVNX and VS1 test series were conducted in the Small Magazine (2$^{nd}$ Deck) and Medium Magazine (3$^{rd}$ Deck) constructed aboard the ex-USS *SHADWELL* for the CVNX test series. The details of the magazine design and the instrumentation have been discussed previously [2] and will only be discussed briefly here. The specific nightvision camera and filter combinations tested are indicated in Table 1. The final test matrices for the VS1 and CVNX test series are included in Tables 2 and 3. The source locations for the VS1 tests are given in the middle column of Table 2, Source Location in Magazine. The numbers in parentheses indicate the general location within the magazine and are defined in Reference 4. The source locations for CVNX are given in Reference 8. Table 3 gives the specific details of each CVNX fire source, see Reference 3 for further information. For reference with regards to the wood crib fires, four 12"x12"x4" cardboard boxes filled with 1 m$^2$ of paper each produced a peak output of approximately 70 kW [9]. Filtered long wavelength-response, or nightvision, cameras previously described [6] were co-located in the magazines with the commercial VIDS cameras at locations 1 – 4, as indicated in Figures 1 and 2. Figures 1 and 2 were adapted from References 2 and 3 and reflect the magazine detector configurations for the VS1 test series, however the camera locations did not change for the CVNX test series. The video output of the nightvision cameras was routed to the ship's control room. In the control room, the video signals were sent to a time generator and the time-stamped product was recorded on videocassettes by a bank of VCRs. All processing of the nightvision video was done after the fact using various analysis techniques and algorithms that will be outlined in the Results and Discussion sections of this report.

Table 1 – CVNX and VS1 Camera Details

| | Camera Type | LP Filter Cutoff |
|---|---|---|
| Small Magazine | | |
| Position 1 (A) | Sony DCR-TRV27 | 720 nm |
| Position 2 (B) | CSi-SPECO CVC-130R | 720 nm |
| | | |
| Medium Magazine | | |
| Position 3 (A) | CSi-SPECO CVC-130R | 720 nm |
| Position 4 (B) | CSi-SPECO CVC-130R | 850 nm |

## Table 2 - Final Test Matrix for VS 1 Test Series

| Test | Magazine | Source Location in Magazine | Fire Source | Ventilation (ACH)[1] |
|---|---|---|---|---|
| VS1-1 | Small | FR23 OH beam –0.6m from port side bulkhead. Cables on flange of OH beam 0.08m below the overhead (1) | Cable Bundle | NV[2] |
| VS1-2 | Small | FR23 OH beam –0.6m from port side bulkhead. Cables on flange of OH beam 0.08m below the overhead (1) | Cable Bundle | 12 |
| VS1-3 | Small | Throughout test compartment (primarily at FR25 starboard) | People working | NV |
| VS1-4 | Small | FR25 – 0.5m from starboard bulkhead. Cables on aft flange of OH beam 0.3m below the overhead (2) | Cable Bundle | NV |
| VS1-5 | Small | FR25 – 0.5m from starboard bulkhead. Cables on aft flange of OH beam 0.3m below the overhead (2) | Cable Bundle | 12 |
| VS1-6 | Small | Throughout and ~Center of test compartment | Waving Towel | NV |
| VS1-7 | Small | FR24 on deck – 2.75m aft of the forward bulkhead on the port side (4) | Cable Bundle | NV |
| VS1-8 | Small | FR24 on deck – 2.75m aft of the forward bulkhead on the port side (4) | Cable Bundle | 12 |
| VS1-9 | Small | FR27 on deck – aft-port corner (3) | Cardboard Boxes | NV |
| VS1-10 | Small | FR27 on deck – aft-port corner (3) | Cardboard Boxes | 12 |
| VS1-11 | Small | Center of Compartment-1.4m from the starboard bulkhead, 3.4m forward of the aft bulkhead (5) | Cardboard Boxes | NV |
| VS1-12 | Small | Center of Compartment-1.4m from the starboard bulkhead, 3.4m forward of the aft bulkhead (5) | Cardboard Boxes | 12 |
| VS1-13 | Small | FR24 on deck – 2.75m aft of the forward bulkhead on the port side (4) | Lactose/ Chlorate | NV |
| VS1-14 | Small | Center of Compartment-1.4m from the starboard bulkhead, 3.4m forward of the aft bulkhead (5) | Lactose/ Chlorate | NV |
| VS1-15 | Small | FR27 on deck-1.4m from the starboard side, 3.4m forward of the aft bulkhead (5) | Lactose/ Chlorate | 12 |
| VS1-16 | Small | FR 22 Bulkhead port side (6) | Grinding Painted Steel | NV |
| VS1-17 | Small | FR 22 Bulkhead port side (6) | Grinding Painted Steel | 12 |
| VS1-18 | Small | Center of Compartment-1.4m from the starboard bulkhead, 3.4m forward of the aft bulkhead (5) | Torch Cut Steel | 12 |
| VS1-19 | Small | Center of Compartment-1.4m from the starboard bulkhead, 3.4m forward of the aft bulkhead (5) | Welding Steel | 12 |
| VS1-20 | Small | Center of Compartment-1.4m from the starboard bulkhead, 3.4m forward of the aft bulkhead (5) | Saw Cutting Steel | 12 |
| VS1-21 | Medium | FR24 on deck, against the port-side of the vestibule (9) | Cardboard Boxes | NV |
| VS1-22 | Medium | FR24 on deck, against the port-side of the vestibule (9) | Cardboard Boxes | 12 |
| VS1-23 | Medium | FR29 on deck, 0.45 m port of centerline beam (10) | Cardboard Boxes | NV |
| VS1-24 | Medium | FR29 on deck, 0.45 m port of centerline beam (10) | Cardboard Boxes | 12 |
| VS1-25 | Medium | Between FR 26 and FR27 on deck, against port bulkhead (8) | Lactose/ Chlorate | NV |
| VS1-26 | Medium | Between FR 26 and FR27 on deck, against port bulkhead (8) | Lactose/ Chlorate | 12 |
| VS1-27 | Medium | FR28 on deck, centerline of compartment against cabinets (11) | Lactose/ Chlorate | NV |
| VS1-28 | Medium | FR28 on deck, centerline of compartment against cabinets (11) | Lactose/ Chlorate | 12 |
| VS1-29 | Medium | Forward section of port bulkhead, between FR 24 and 25 | Grinding Steel | NV |
| VS1-30 | Medium | FR28 on deck, centerline of compartment (11) | Torch Cut Steel | 12 |
| VS1-31 | Medium | FR28 on deck, centerline of compartment (11) | Welding Steel | 12 |
| VS1-32 | Medium | Throughout and between FR28 and FR29, centerline of compartment (11) | Waving Towel | 12 |
| VS1-33 | Medium | Throughout test compartment | People working | 12 |
| VS1-34 | Medium | FR28 - Cables on flange of OH beam, 1.3 m from port bulkhead, 0.3 m below OH (7) | Cable Bundle | NV |
| VS1-35 | Medium | FR28 - Cables on flange of OH beam, 1.3 m from port bulkhead, 0.3 m below OH (7) | Cable Bundle | 12 |
| VS1-36 | Medium | FR29 on deck, 0.45 m port of centerline beam (10) | Cable Bundle | NV |
| VS1-37 | Medium | FR29 on deck, 0.45 m port of centerline beam 100% power (10) | 500 W Cable Bundle | NV |
| VS1-38 | Medium | FR29 on deck, 0.45 m port of centerline beam 100% power (10) | 500W Cable Bundle | 12 |
| VS1-39 | Medium | FR26 - Cables on flange of OH beam, 2.6 m from port bulkhead, 0.3 m below OH (12) | 500 W Cable Bundle | NV |
| VS1-40 | Medium | FR26 - Cables on flange of OH beam, 2.6 m from port bulkhead, 0.3 m below OH (12) | 500 W Cable Bundle | 12 |

[1] ACH = Air Changes per Hour [2] NV = Not Ventilated

Table 3 — Test Matrix for CVNX Test Series 2 Magazine Tests

| Test | Magazine | Peak Avg. Bulkhead Temp. (°C (°F)) | Nominal Calculated Wood Crib Fire Size (kW (BTU/sec)) | Ventilation (ACH)[1] |
|---|---|---|---|---|
| CVNX-31 | 2nd Deck | ~155 (311) | | NV |
| CVNX-32 | 2nd Deck | ~315(599) | | NV |
| CVNX-33 | 2nd Deck | ~305 (581) | | NV |
| CVNX-34 | 2nd Deck | ~315 (599) | | 12 |
| CVNX-35 | 2nd Deck | ~360 (680) | | NV |
| CVNX-36 | 2nd Deck | ~355 (671) | | 12 |
| CVNX-37 | 2nd Deck | | 25 (24) | NV |
| CVNX-38 | 2nd Deck | | 25 (24) | NV |
| CVNX-39 | 2nd Deck | | 100 (95) | NV |
| CVNX-40 | 2nd Deck | | 100 (95) | 12 |
| CVNX-41 | 2nd Deck | | 100 (95) | NV |
| CVNX-42 | 2nd Deck | | 250 (237) | NV |
| CVNX-43 | 2nd Deck | | 250 (237) | 12 |
| CVNX-44 | 3rd Deck | ~263 (505) | | NV |
| CVNX-45 | 3rd Deck | ~259 (498) | | 12 |
| CVNX-46 | 3rd Deck | ~254 (489) | | NV |
| CVNX-47 | 3rd Deck | ~270 (518) | | 12 |
| CVNX-48 | 3rd Deck | ~342 (648) | | NV |
| CVNX-49 | 3rd Deck | ~321 (610) | | 12 |
| CVNX-50 | 3rd Deck | | 25 (24) | NV |
| CVNX-51 | 3rd Deck | | 100 (95) | NV |
| CVNX-52 | 3rd Deck | | 100 (95) | 12 |
| CVNX-53 | 3rd Deck | | 50 (47) | NV |
| CVNX-54 | 3rd Deck | | 250 (237) | NV |
| CVNX-55 | 3rd Deck | | 250 (237) | 12 |

[1] ACH = Air Changes per Hour [2] NV = Not Ventilated

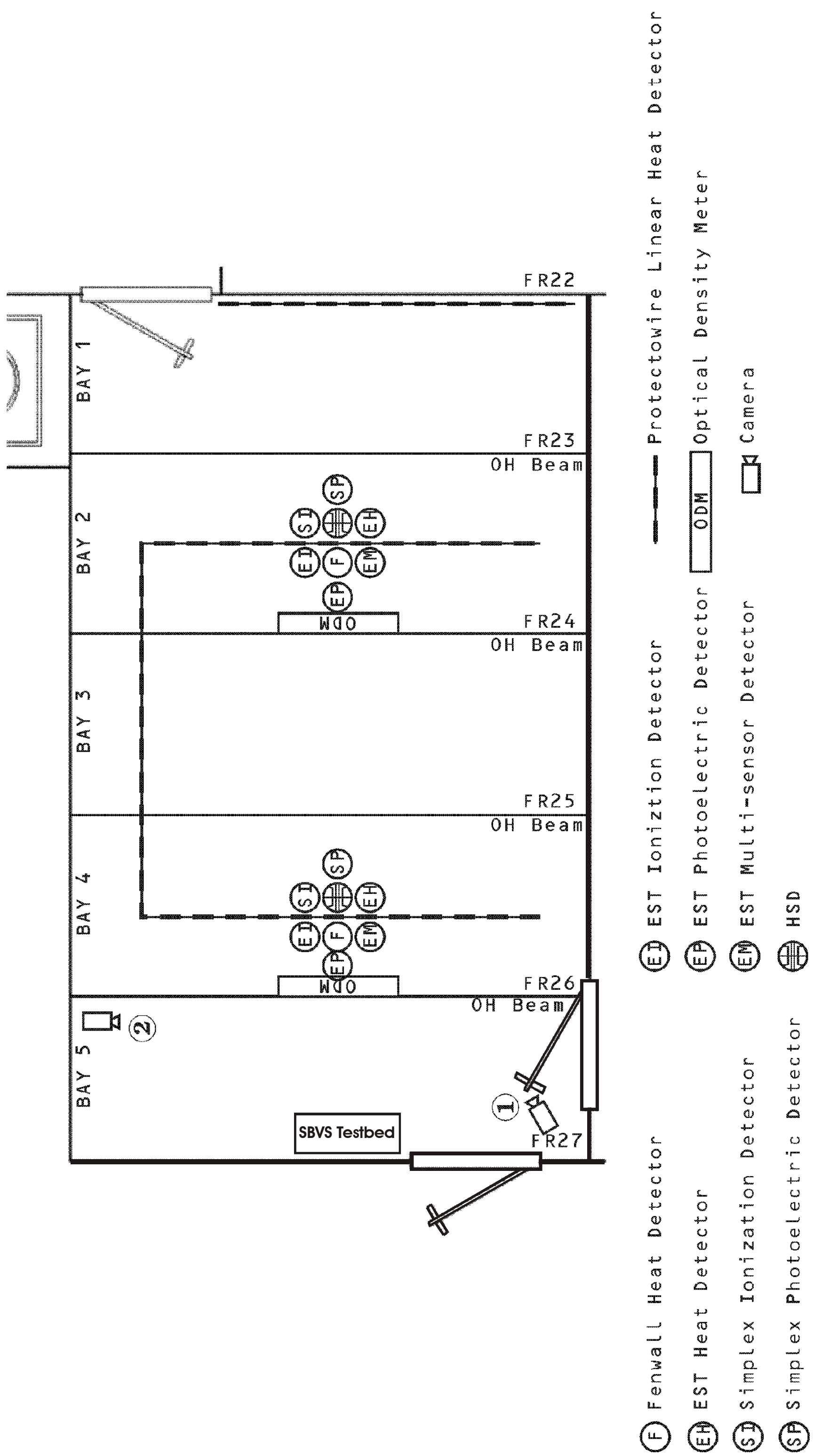


Fig. 1 – VS1 Detector Locations for the 2nd Deck Magazine (Small Magazine)

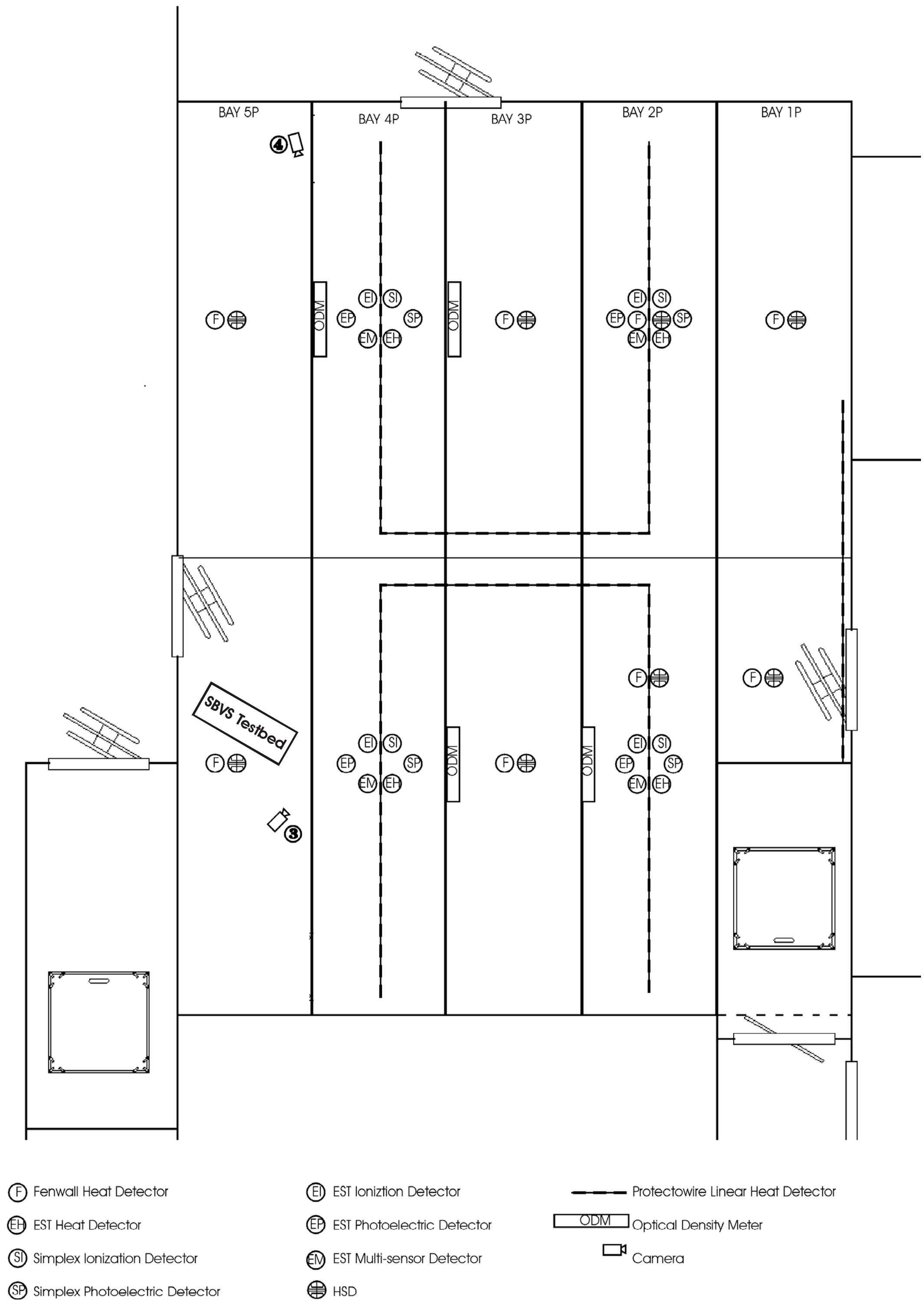


Fig. 2 – VS1 Detector Locations for the 3rd Deck Magazine (Medium Magazine)

## ALGORITHMS AND VIDEO ANALYSES

One method for evaluating the nightvision video for the detection of fire, smoke, and hot objects is to compare the nightvision video to the results from the commercial VIDS using the regular cameras. As part of the CVNX and VS1 tests, commercial VIDS were evaluated and the results have been compiled in a preliminary report [4]. In order to permit a more quantitative comparison, the nightvision video has been processed using several algorithms. Two companies that have MV-based systems being tested in the Volume Sensor effort using the regular video, Fastcom Technologies and AxonX, have used their proprietary algorithms to analyze some of the nightvision video collected during the CVNX and VS1 test series. The results of their analyses will be discussed below without further description of their methods since they are proprietary. In addition, as part of the Volume Sensor Program, a luminosity-based algorithm has been developed at the Naval Research Laboratory (NRL) and used to analyze the nightvision videos from these tests. In the next section, the algorithm development and implementation is described and then the test results are discussed.

## LWVD – ALGORITHM AND IMPLEMENTATION

### Algorithm Design

In order to analyze the video collected from the filtered nightvision cameras in a quantitative manner and to allow for comparison with the commercial VIDS, a simple algorithm based on the total luminosity, or brightness, of the video image was developed and implemented in a software package written within the Volume Sensor Program effort at NRL. The algorithm currently employed represents only the initial effort in what will ultimately be a more sophisticated package. The version described below is based solely on total luminosity, but future versions of the algorithm will be developed using the spatial and temporal variations of the video. The algorithm described here was developed to generate threshold-based alarms from the total luminosity of the video frame to facilitate comparison with the regular camera images and with the commercial VIDS. The LWVD software package was designed to exploit the unique nature of the nightvision video in terms of low background intensity and high contrast imaging of flaming or hot objects. The goals of the algorithm and its implementation included not only producing a real-time LWVD VIDS, but also providing a method for off-line, post-processing of video from these and other test series, which added additional constraints and requirements.

As discussed in previous sections, nightvision cameras are more sensitive to hot objects than are regular video cameras. Smoke, though readily discernible with regular cameras, is generally near room temperature and therefore does not emit strongly above the ambient background level in the wavelength region that is detected with nightvision cameras. Well-defined external illumination would be required to reliably detect smoke in a compartment with nightvision cameras. The Volume Sensor Program has chosen to concentrate their initial development efforts on fire and hot object detection algorithms for the nightvision cameras. The design specifications for the LWVD package may be grouped into two categories: general design criteria applicable to any VIDS, and criteria specific to nightvision cameras and video. General criteria for VIDS design include high-speed processing, low computational complexity, nuisance source rejection, and flexibility with regards to environmental and camera conditions.

Real-time video generates a vast amount of data. For example, a video stream of 640 x 480 pixel video images received at the standard rate of 30 frames per second (FPS) generates 307 kB of data per image, or 9.2 MB of data per second. While real-time processing is not a requirement for the post-processing of the CVNX and VS1 test data, an efficient processing algorithm should be considered. A trade-off exists between the number of frames the algorithm can process per second and the complexity of the processing possible for a fixed amount of processing bandwidth. Additionally, algorithms that require fewer video frames per second could potentially process more concurrent video streams simultaneously.

A successful algorithm should be able to discriminate background activities and non-alarm events from alarm events and only generate an alarm condition for the alarm events. Relevant examples to the CVNX and VS1 tests series include people and machines working within the camera FOV, performing tasks such as welding and grinding, and evolving light levels such as changes in the ambient lighting level of the compartment or flickering light levels from damaged light fixtures.

For the greatest flexibility, ease of deployment, and overall robustness of operation, the viability of the algorithm should depend as little as possible on the details of the equipment used to collect the video, such as the manufacturer and model of the camera used, the camera settings, or the background light level. Other parameters, which could affect the operation/viability of the algorithm, include the resolution of the collected video resolution and the image quality of the received video signal.

Fires and hot objects manifest in a more direct manner in nightvision video than in regular video. Detection of Near-InfraRed (NIR) emission from flaming fires is not limited to the camera FOV, but can also be detected in reflection. Sources within the camera FOV appear as very bright objects, exhibit “flicker,” or time-dependent intensities, and tend to grow in spatial extent as time progresses. Regions of the image that are common to both the camera FOV and within Line of Sight (LOS) of the source will reflect NIR emission from the source to the camera. These regions will appear to the viewer as emitting. For sufficiently large fire sources, the heat generated by the source can increase the temperature of the compartment bulkheads sufficiently that a nightvision camera can detect the change from an adjacent compartment. The temporal and spatial evolution of sources imaged by this absorption / reemission scheme are different than those for directly detected sources due to the moderating effect of the intermediate source. Examples will be shown and discussed in later sections of this report.

## Luminosity

The luminosity of an image, $L$, is defined for the LWVD algorithm as the summation of the intensity of each pixel normalized for the image dimensions. The luminosity has several properties that make it an attractive quantity for evaluating the collected nightvision camera video. First, summation over a matrix of pixel intensities is a simple, fast operation to perform. Summation will tend to average out any random variations in low-light level images due to increased CCD exposure times. Any degradation of the image quality will be moderated as all the captured intensity will be detected by some CCD element and the summation removes any spatial information. Second, the luminosity captures the fire characteristics described above. Luminosity directly tracks changes in the overall brightness of the video frame. Luminosities of sequential video frames may be compactly stored for use with signal processing filters and to examine time series for spatial growth of non-flickering, bright regions. The luminosity of the current video frame may be compared to the luminosity of a reference frame to allow for background subtraction. The luminosity profiles for a flaming fire and an adjacent space (heated bulkhead) source are shown in Figures 3a and 3b. Finally, nuisance sources that do not emit NIR radiation and/or do not greatly affect the overall brightness of the video image are naturally rejected. For example, people moving about in the camera's field-of-view induce almost no change in the luminosity as shown in Figure 3c. A similar approach was suggested by Wittkopp et al. [10] for image analysis and event classification for fire and smoke events in aircraft cargo holds using regular video cameras.

Some fire-like nuisance sources dramatically affect the total brightness of the image and the resultant luminosity. Welding and grinding sources are examples of such sources, as shown for a welding event in Figure 3d. The luminosity profiles for such events, however, exhibit different frequency components than those for fire sources. Other nuisance sources affect the reference luminosity by changing the background illumination. For example, lights being turned on or off dramatically changes the background luminosity value.

## LWVD Algorithm

The LWVD algorithm detects fire events by comparing the luminosity, $L$, of the current video frame to the sum of a reference luminosity, $L_b$, and an alarm threshold, $L_{th}$, tracking the number of frames with $L > L_b + L_{th}$ and then alarming when a persistence criteria is met. Flowcharts of the LWVD algorithm are shown in Figure 4.

The analysis of the CVNX and VS1 tests has shown that a fire event generally increases the luminosity of a video frame by an amount independent of the background illumination. The reference luminosity is chosen as the luminosity of a frame 30 seconds from the beginning of the .AVI file, generally early enough to consist entirely of background features. To mitigate the effects of large variations observed in the background luminosity, a nonlinear relationship between the reference $L_b$ and the alarm threshold is used:

$$L_{th} = 2\sqrt{L_b}$$

which yields proportionally smaller thresholds for larger background luminosities.

Persistence of the $L > L_b + L_{th}$ condition is used to discriminate against spurious bright nuisances such as a flash of light or a reflective object rapidly moving through the space. Persistence is tracked with the "Alarm Count" shown in Figure 4. A frame with a luminosity larger than $L_b + L_{th}$ will increment the alarm count, while a frame with luminosity smaller than $L_b + L_{th}$ will decrement this count, but never to a value less than zero. An event alarm is generated when the alarm count reaches 75. Given the rate of video frame processing, the algorithm's minimum response time for event detection is 5 seconds. A maximum response, or reset alarm, time is not necessary for the analysis of recorded tests.

The LWVD algorithm has been implemented in Mathworks' numerical analysis software suite, Matlab v6.5 (Release 13). Matlab includes functions for accessing video recorded in the .AVI format, and the Image Acquisition Toolbox for handling real-time video streams. One version of the LWVD software was used to generate event alarms from the recorded CVNX and VS1 test series video. Another version of the LWVD software with an interactive GUI for controlling real-time video sources was used for the blackbody temperature comparison.

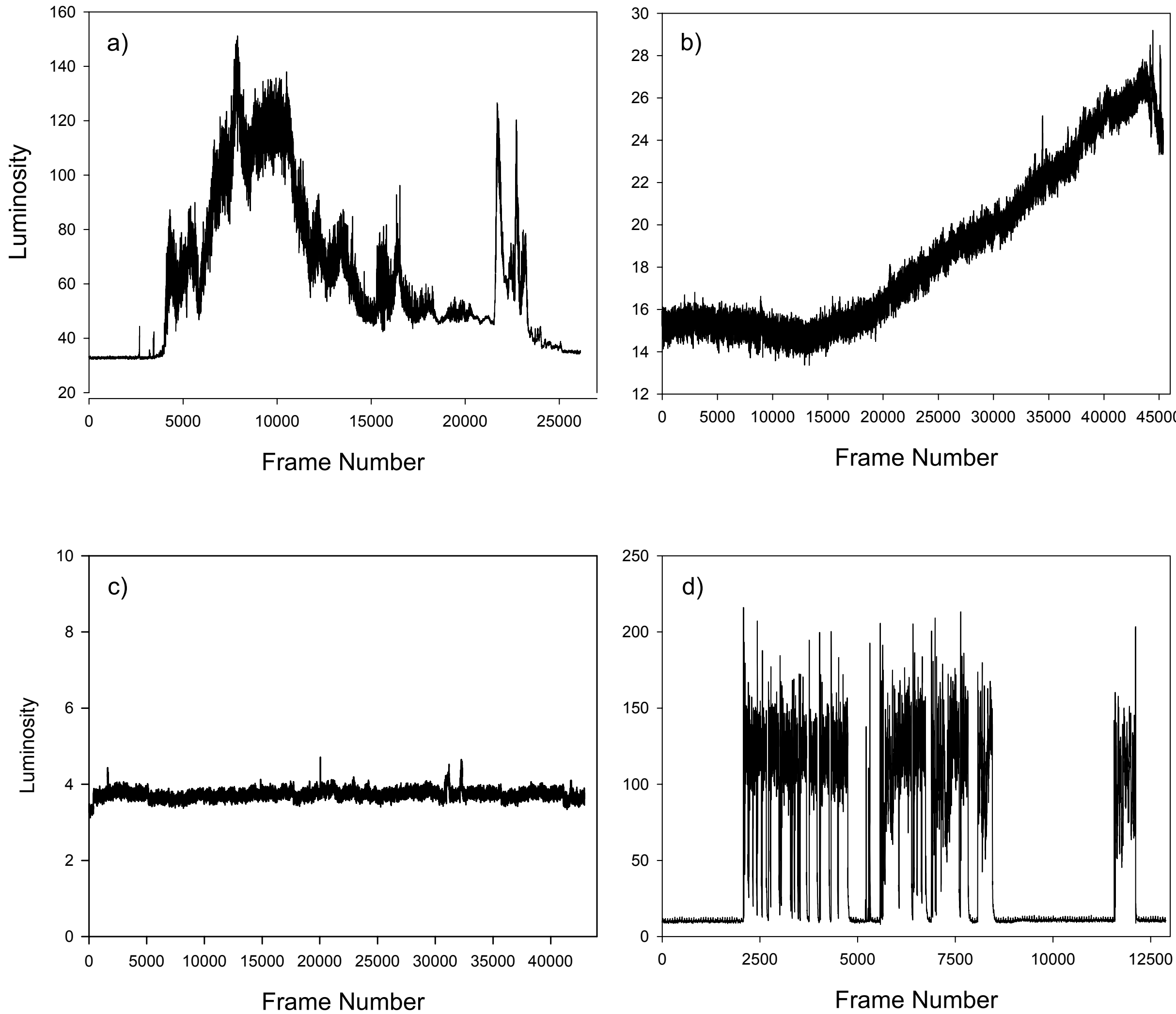


Fig. 3 – Luminosity versus frame number plots for a) a flaming fire, b) a bulkhead heated by a fire in an adjacent space, c) people working in a space, and d) a crew member welding steel

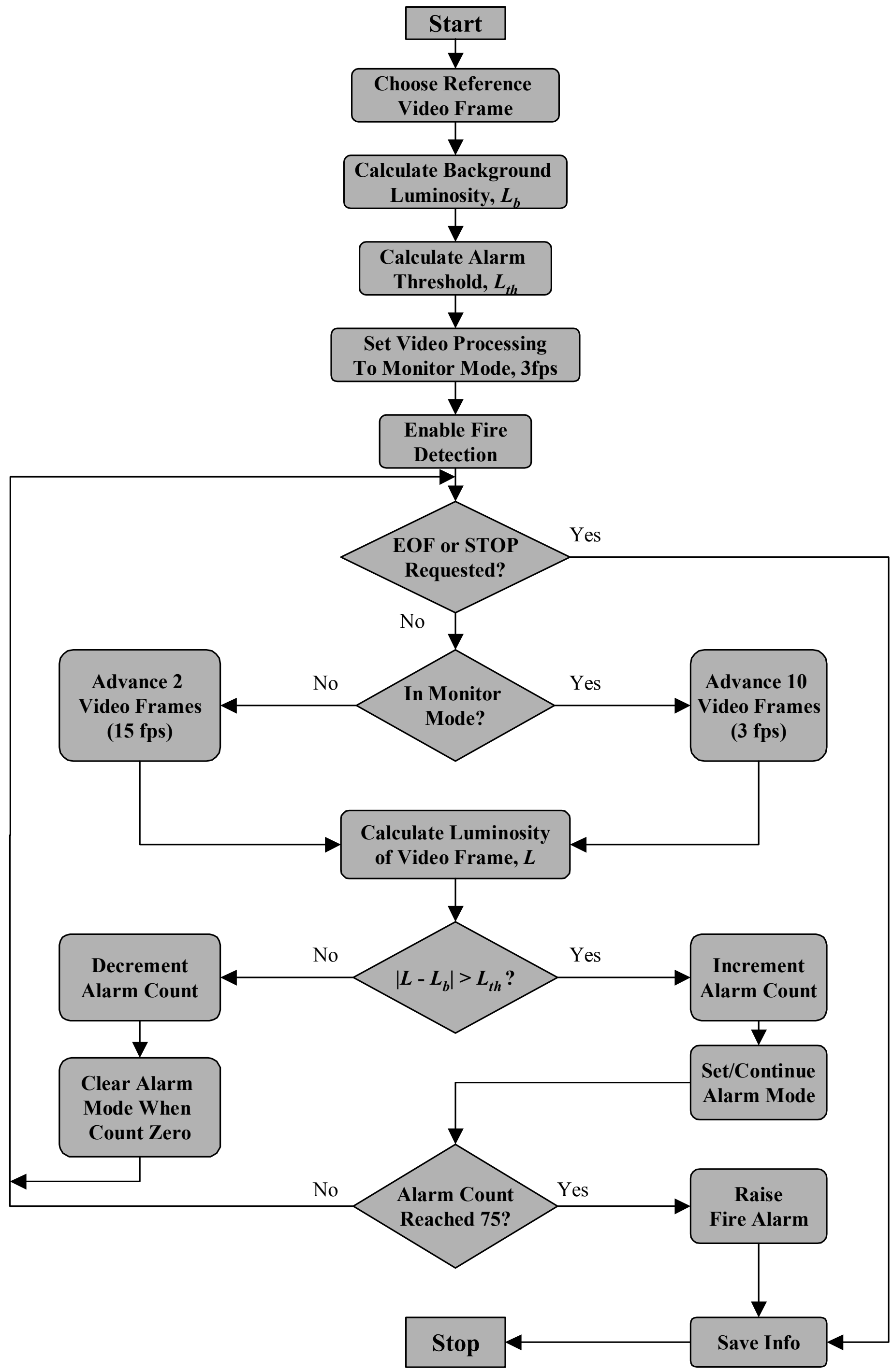


Fig. 4 – LWVD Algorithm Processing Flowchart

## RESULTS

### Archived Test Video

For tests CVNX-31 through -55 and VS1-1 through -40, video was recorded from cameras placed at two locations per magazine with two different types of cameras at each location. Standard video cameras, specified to work with the commercial VIDS under evaluation as part of the Volume Sensor (VS) program, were installed in the two aft corners of each magazine compartment. See Figures 1 and 2 for the specific mounting locations; mounting height was approximately 8 ft above the deck. In addition, a nightvision camera, configured as detailed in Table 1, was installed at each camera location. Location 1 and 3 cameras, denoted as "A" in Table 4, were mounted in the starboard aft corner facing either forward or to port as indicated in Table 4. Location 2 and 4 cameras, denoted as "B" in Table 4, were mounted in the port aft corner facing either forward or to starboard as indicated in Table 4. Several individual CVNX videos were not recorded during the test series and are so noted in Table 4. The analysis of regular camera video-based event detection has been discussed elsewhere [4, 8]. As the focus of this report is on the performance of the nightvision cameras, the regular video will only be discussed in comparison to the nightvision video.

Test videos from the CVNX and VS1 test series are part of the fire event database of the Volume Sensor Program. The tests were originally recorded on VHS videocassettes and then digitized and recorded on DVD-ROM for long-term storage [11]. This database of video was used as the off-line video source for the analysis presented in this report. The database consists of recorded video stored in a compressed .AVI video file format on DVD-ROM disks. The video files can be used directly from the DVD-ROM disk or transferred to another system prior to use. Future test recording is being migrated to an all-digital real-time recording method. The method and software employed for recording and digitizing test video has been described previously [12].

Table 4 – Camera Orientation for Individual Tests[1]

| Test | Magazine | Video/file | Camera Position | | | |
|---|---|---|---|---|---|---|
| | | | A | | B | |
| | | | Position | Direction | Position | Direction |
| VS1 | Small | VS1-01 to VS1-20 | Starboard | Forward | Port | Starboard |
| | Medium | VS1-21 to VS1-40 | Starboard | Forward | Port | Starboard |
| CVNX | Small | CVNX-31 to CVNX-41 | Starboard | Forward | Port | Forward |
| | Medium | CVNX-44 to CVNX-50 | Starboard | Port | Port | Starboard |

[1] Video for tests CVNX-42, CVNX43, and CVNX-55 were not recorded.

## General Results

Several features of nightvision video were apparent from monitoring the video streams during the tests. First, flaming fires are more sensitively detected with nightvision cameras than regular cameras due to the increased emission of hot objects at the longer wavelengths detected by the nightvision cameras. NIR emission from flames is easily visible to the nightvision cameras, which is not always the case for regular video. Figure 5 consists of several panels of extracted images from the videos to demonstrate this point. Panels a) and b) show the test compartment for test VS1-21 from the camera 3 position for the regular and the filtered nightvision cameras, respectively, prior to source ignition.[3] These images could serve as the initial reference images for spatially resolved algorithmic processing. Panels c) and d) contain images from the same cameras several minutes later while the cardboard box flaming source is burning in the lower right hand corner, within the camera FOV for the nightvision camera and just out of the camera FOV for the regular camera. In both cases indications of the flame source can be seen in the video. The orange visible emission from the flame can be seen reflecting off the surface of the nearest cabinet. For the nightvision camera, the source is within the camera FOV and has clearly illuminated the camera's CCD. Additionally, the entire wall behind the source, the same cabinet discussed for the regular camera, and the nearby pillar are well illuminated in the NIR. The use of the LP filter with the nightvision cameras dramatically increases the contrast and sensitivity for flaming or hot objects, making event detection a much simpler task.

Figure 6 presents images similar to those in Figure 5, but for a source that is completely outside the FOV of all cameras. The source for test VS1-10 was several cardboard boxes placed on the deck against the aft bulkhead. This position is below and behind the FOV of camera position 2. Panels a) and b) show the pre-test, or ambient condition of the compartment of both the regular and nightvision cameras. Panels c) and d) contain images acquired several minutes after source ignition when the source was fully engulfed in flame. Little or no difference can be seen between the regular images, with the exception of what appears to be smoke in the upper left-hand portion of the image. There is a marked difference between the two nightvision images, the NIR emission from the flame has completely illuminated the entire area within the camera FOV. In the nightvision video, the NIR illumination fluctuates with the same temporal profile as the flame itself. This suggests that reflected NIR light could be used to detect flames that are out of the camera FOV based on time-series analysis of the camera video alone.

A second general observation is the ability of the nightvision cameras to act as an inexpensive form of thermal-imaging camera. In fact, they worked so well that during the CVNX test series the ex-USS *SHADWELL* control room crew used the nightvision cameras as monitors for the progress of tests involving fires in adjacent compartments. For tests CVNX-31 through -36 and CVNX-44 through -49, a heptane spray fire was set up outside the test magazine and directed at a magazine bulkhead to simulate a fire in an adjacent compartment [8].

In this case, rather than detecting the reflected radiation from a fire, the elevated temperature of a proximate structure / bulkhead can be seen by its NIR emission. Assuming blackbody emission, the NIR emission from the bulkhead should depend on the observed temperature. In the following sections of this report, the observed luminosity is compared to the measured bulkhead temperature. Figure 7 contains several still images from the nightvision camera at position 4 in the medium magazine during test

[3] All video sequences specifically discussed in the text are included in their entirety on the enclosed CD.

CVNX-49. As time passes, from panel a) to panel d), the NIR emission of the bulkhead is seen to grow in both size and intensity, indicating higher bulkhead temperatures.


a) Regular camera at start of test.

b) Nightvision camera at start of test.

c) Regular camera during period of open flame just outside the camera FOV.

d) Nightvision camera during period of open flame within the camera FOV.

Fig. 5 – Camera video from VS1-21 test, camera position 3. Regular and nightvision still images showing the compartment before test ignition and during a flaming event within the nightvision camera FOV and nearly within the regular camera FOV

A comparison of the measured total luminosity (intensity) of the image to the actual bulkhead temperature as recorded by thermocouples (TC) will be presented in a following section of this report. Comparison to the regular camera video for test CVNX-49 is not possible as the corresponding video recording was not made or is missing. A more direct comparison is possible for a similar, if less spectacular, test for which there is video from both the starboard regular and nightvision cameras. Still images are presented in Figure 8.

Panels a) and b) of Figure 8 show a still image from both the regular and nightvision cameras taken at the beginning of the VS1-34 test from camera position 1. Panels c) and d) show still images from the same cameras approximately 24 minutes into the test. There is little or no change in the regular camera image, but the nightvision camera clearly shows the hot bulkhead, even if the view is partially obstructed. Panels e) and f) are still images from the end of test VS1-34, approximately 49 minutes after ignition. Some smoke is now clearly visible in the regular camera view. The nightvision camera image has not changed significantly from the image taken at the 24-minute point, but the hot bulkhead is still clearly visible.

a) Regular camera at start of test.

b) Nightvision camera at start of test.

c) Regular camera during period of open flame outside the camera FOV.

d) Nightvision camera during period of open flame outside the camera FOV.

Fig. 6 – Camera video from VS1-10 test, camera position 2. Regular and nightvision still images showing the compartment before test ignition and during a flaming event outside the camera FOV

One final general observation is that while the nightvision cameras are decidedly more sensitive to flames and other hot objects, the LP filter, which suppresses the visible image, makes the detection of smoke more difficult. Since smoke particles are cold, approaching room temperature, their NIR emission is similar to that of the background. The detection of smoke will require illumination or some other approach. In an upcoming test series at Hughes Associates [13], an NIR illuminator will be tested and the effects on the detection of smoke with nightvision cameras evaluated further.

a) Nightvision camera at start of test.

b) Nightvision camera 00:04:39 into test.

c) Nightvision camera 00:12:17 into test.

d) Nightvision camera 00:20:43 into test, effectively the end of the test.

Fig. 7 – Camera video from CVNX-49 test, camera position 4. Nightvision still images showing the compartment before test ignition and at three times during the test

a) Regular camera at start of test.

b) Nightvision camera at start of test.

c) Regular camera 00:24:36 into test.

d) Nightvision camera 00:24:17 into test.

e) Regular camera 00:49:27 into test.

f) Nightvision camera 00:49:10 into test.

Fig. 8 – Camera video from CVNX-34 test, camera position 1. Regular and nightvision still images showing the compartment before test ignition and at two times during the test

## ANALYSIS

### LWVD-BASED ALARM TIMES

Fire tests from the VS1 and CVNX test series were analyzed offline with the LWVD algorithm from database video stored in the .AVI file format and compressed with the motion-JPEG based video codec from LEADTools, Inc. [12]. For offline processing, the LWVD software was modified to accept a video stream from an .AVI file and the GUI was removed. Matlab includes software for dynamically accessing compressed .AVI files using resources available in the Windows operating system. The Matlab software converts the video data stored in the .AVI file into a stream of Red, Green, Blue (RGB) color matrices suitable for numerical processing by the LWVD algorithm. The results from the LWVD algorithm are tabulated in Tables 5 and 6 for each test series and compared with the commercial video fire detection systems below.

The columns in Table 5 list, in order from left to right, the following information with examples from test CVNX-31 in parentheses: Test ID (CVNX-31), Fire Source – source material (Heptane Spray), Source Type – Nuisance, Flaming, Smoldering, Adjacent Compartment (Adjacent Compartment), Ignition time – time of day when the source was ignited in a 24-hour time format (10:06:51), Camera A Alarm Time - time in seconds after ignition when the LWVD algorithm alarmed, if no alarm occurred a value of No is entered (No), Camera B Alarm Time (No). The final column includes the alarm time for the commercial VIDS from Fastcom Technologies, the SFA. The SFA was monitoring the regular video cameras installed in the test compartments as previously described [2-4,7,8]. The time reported is for the fastest response (camera) if more than one camera went into alarm. If no alarm was generated, the value entered is "No", (420). The FireSentry VSD-8 system was present for all CVNX tests, but did not generate any alarms. For several tests, one or more VIDS was not available to observe the test. In these cases, the appropriate cells are shaded gray and the test is not included in any statistics generated.

The first six columns in Table 6 are the same as for Table 5. A variant build of the Fastcom Technologies SFA software package was developed under contract for this program with additional user-adjustable settings for contrast and brightness levels for initial proof-of-concept work on integrating the nightvision cameras into the SFA framework [14]. AxonX additionally post-processed some of the VS1 test sequences at NRL's request with their SigniFire product. Column 7 and 8 report the alarm times from AxonX's SigniFire program and from Fastcom's SFA variant respectively for the VS1 Test Series. Tests that are grayed out in these columns were not processed and are not counted in any statistics generated for the corresponding VIDS. The final three columns list the alarm times for the three commercial VIDS operating during the VS1 test series using the regular video cameras.

The analysis of the results from Tables 5 and 6 will be presented in several sections addressing individual points for clarity. First, results regarding the selection of cutoff wavelength for the nightvision camera's LP filter will be discussed. The next section compares the probability of alarm and false alarm statistics for the LWVD Algorithm when evaluating each camera in the same compartment and separately and then as a fused pair. The LWVD Algorithm results are compared to the response times for commercial VIDS using regular cameras. For a select set of VS1 data, the commercial VIDS have post-processed the nightvision video. The results are compared to the LWVD results. Finally, laboratory measurements made regarding the temperature sensitivity, or calibration, of the nightvision cameras are discussed and compared with the TC temperature results from the CVNX-49 test.

Table 5 – Results for the CVNX Test Series

| Test ID | FIRE SOURCE | SOURCE TYPE | IGNITION TIME (HH:mm:ss) | LWVD Cameras | | Commercial VIDS |
|---|---|---|---|---|---|---|
| | | | | Camera A ALARM TIME (seconds) | Camera B ALARM TIME (seconds) | SFA ALARM TIME (seconds) |
| CVNX-31 | Heptane Spray | Adjacent Compartment | 10:06:51 | No | No | 420 |
| CVNX-32 | Heptane Spray | Adjacent Compartment | 13:12:26 | 517 | 657 | No |
| CVNX-33 | Heptane Spray | Adjacent Compartment | 09:25:55 | No | No | No |
| CVNX-34 | Heptane Spray | Adjacent Compartment | 12:05:39 | No | No | No |
| CVNX-35 | Heptane Spray | Adjacent Compartment | 13:55:28 | No | 1026 | No |
| CVNX-36 | Heptane Spray | Adjacent Compartment | 15:56:30 | No | No | 186 |
| CVNX-37 | Wood Crib | Flaming | 11:25:25 | 19 | 17 | 162 |
| CVNX-38 | Wood Crib | Flaming | 13:09:38 | 32 | 30 | 90 |
| CVNX-39 | Wood Crib | Flaming | 14:36:30 | 5 | 5 | 258 |
| CVNX-40 | Wood Crib | Flaming | 08:25:56 | 16 | 19 | 72 |
| CVNX-41 | Wood Crib | Flaming | 10:02:34 | 23 | 26 | 222 |
| CVNX-42 | Wood Crib | Flaming | 12:25:46 | | | 276 |
| CVNX-43 | Wood Crib | Flaming | 13:47:51 | | | |
| CVNX-44 | Heptane Spray | Adjacent Compartment | 10:46:56 | 398 | No | 204 |
| CVNX-45 | Heptane Spray | Adjacent Compartment | 13:29:47 | 1692 | No | No |
| CVNX-46 | Heptane Spray | Adjacent Compartment | 15:02:36 | 1229 | No | No |
| CVNX-47 | Heptane Spray | Adjacent Compartment | 08:38:22 | 1651 | No | No |
| CVNX-48 | Heptane Spray | Adjacent Compartment | 11:06:05 | 1101 | 1247 | No |
| CVNX-49 | Heptane Spray | Adjacent Compartment | 13:47:41 | 1271 | 1063 | No |
| CVNX-50 | Wood Crib | Flaming | 12:19:28 | 24 | 13 | No |
| CVNX-51 | Wood Crib | Flaming | 13:37:15 | 300 | 10 | No |
| CVNX-52 | Wood Crib | Flaming | 14:46:49 | 367 | 11 | 24 |
| CVNX-53 | Wood Crib | Flaming | 09:50:39 | 540 | 7 | No |
| CVNX-54 | Wood Crib | Flaming | 11:17:35 | 265 | 24 | 48 |
| CVNX-55 | Wood Crib | Flaming | 13:01:45 | | | No |

= This test was not analyzed by this system.

Table 6 – Results for the VS1 Test Series

| | | | | LWVD | | Commercial VIDS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Camera A | Camera B | Nightvision Camera | | Regular Cameras | | |
| Test ID | FIRE SOURCE | SOURCE TYPE | IGNITION TIME (HH:mm:ss) | ALARM (seconds) | ALARM (seconds) | Signifire (seconds) | mean SFA (seconds) | SFA (seconds) | VSD-8 (seconds) | Signifire (seconds) |
| VS1-01 | Cable Bundle | Smoldering | 12:48:00 | No | 1799 | | No | 637 | No | No |
| VS1-02 | Cable Bundle | Smoldering | 14:14:05 | No | No | | No | No | No | No |
| VS1-03 | People Working | Nuisance | 08:38:03 | No | No | | No | No | No | No |
| VS1-04 | Cable Bundle | Smoldering | 09:15:04 | No | 931 | | No | 1221 | No | No |
| VS1-05 | Cable Bundle | Smoldering | 10:16:04 | No | 485 | | No | No | No | 274 |
| VS1-06 | Waving Towel | Nuisance | 11:16:30 | No | No | | No | No | No | No |
| VS1-07 | Cable Bundle | Smoldering | 11:34:08 | 1550 | 839 | | No | No | No | 693 |
| VS1-08 | Cable Bundle | Smoldering | 13:12:08 | 1609 | 1270 | | No | 593 | No | 460 |
| VS1-09 | Cardboard Boxes | Flaming | 14:08:25 | No | 87 | | No | 129 | No | 158 |
| VS1-10 | Cardboard Boxes | Flaming | 14:38:47 | 117 | 41 | 167 | 564 | 214 | No | 111 |
| VS1-11 | Cardboard Boxes | Flaming | 15:12:30 | 62 | 63 | | 74 | 53 | 99 | 90 |
| VS1-12 | Cardboard Boxes | Flaming | 15:47:20 | 42 | 42 | | 5040 | 82 | 112 | 89 |
| VS1-13 | Lactose / Chlorate | Smoldering | 16:44:28 | No | 507 | | No | 496 | 512 | 365 |
| VS1-14 | Lactose / Chlorate | Smoldering | 08:32:45 | 6 | 4 | | No | 27 | No | No |
| VS1-15 | Lactose / Chlorate | Smoldering | 08:56:10 | 50 | 9 | | 187 | 31 | No | 39 |
| VS1-16 | Grinding Steel | Nuisance | 09:23:40 | 30 | No | | 3600 | 32 | No | No |
| VS1-17 | Grinding Steel | Nuisance | 09:46:40 | 120 | No | | 9060 | No | No | No |
| VS1-18 | Torch Cutting Steel | Nuisance | 10:15:02 | 3 | 3 | | No | No | No | No |
| VS1-19 | Welding Steel | Nuisance | 10:48:45 | 7 | 7 | | No | 56 | No | 24 |
| VS1-20 | Saw Cutting Steel | Nuisance | 11:06:40 | No | No | | No | No | No | No |
| VS1-21 | Cardboard Boxes | Flaming | 13:48:40 | 105 | 147 | | No | No | No | 422 |
| VS1-22 | Cardboard Boxes | Flaming | 14:32:15 | 34 | 101 | | 224 | 111 | No | 169 |
| VS1-23 | Cardboard Boxes | Flaming | 08:15:20 | 40 | 39 | | 199 | 201 | No | 114 |
| VS1-24 | Cardboard Boxes | Flaming | 08:50:47 | 20 | 30 | 32 | No | No | No | 79 |
| VS1-25 | Lactose / Chlorate | Smoldering | 09:37:06 | 74 | No | | No | 22 | No | 60 |
| VS1-26 | Lactose / Chlorate | Smoldering | 09:58:35 | 17 | No | | No | 18 | No | 37 |
| VS1-27 | Lactose / Chlorate | Smoldering | 10:40:03 | 16 | No | | No | 55 | No | 101 |
| VS1-28 | Lactose / Chlorate | Smoldering | 11:05:31 | 19 | 69 | | No | No | No | 169 |
| VS1-29 | Grinding Steel | Nuisance | 12:12:03 | No | 99 | | No | No | No | No |
| VS1-30 | Torch Cutting Steel | Nuisance | 12:30:11 | 24 | 25 | | No | No | No | No |
| VS1-31 | Welding Steel | Nuisance | 12:54:02 | 6 | 5 | | 33 | 50 | No | 26 |
| VS1-32 | Waving Towel | Nuisance | 13:13:14 | No | No | | No | No | No | No |
| VS1-33 | People Working | Nuisance | 13:29:00 | No | No | | No | No | No | No |
| VS1-34 | Cable Bundle | Smoldering | 13:55:10 | No | 684 | | No | 567 | No | 248 |
| VS1-35 | Cable Bundle | Smoldering | 14:20:37 | 1530 | No | | No | 394 | No | 246 |
| VS1-36 | Cable Bundle | Smoldering | 08:05:40 | 1806 | No | | No | 792 | No | 536 |
| VS1-37 | 500W Cable Bundle | Smoldering | 08:57:38 | 579 | 579 | | No | 186 | No | 200 |
| VS1-38 | 500W Cable Bundle | Smoldering | 09:36:33 | 708 | 708 | | 680 | 172 | No | 614 |
| VS1-39 | 500W Cable Bundle | Smoldering | 10:16:00 | 1445 | No | | No | No | No | 736 |
| VS1-40 | 500W Cable Bundle | Smoldering | 11:03:00 | 1573 | No | | No | No | No | 516 |

= This test was not analyzed by this system.

Nightvision LP Filter Selection

As shown in Figures 5 – 8, flames within the camera FOV are visible to both regular and nightvision cameras, but are more evident with the nightvision cameras due to both the extended operating wavelength range (to greater than 1000 nm) and the LP filter which attenuates or completely removes the background image. Illumination sources, such as room lights, are designed to emit strongly in the visible portion of the spectrum for obvious reasons. The LP filters used in these tests block wavelengths below either 720 or 850 nm, reducing or eliminating the ambient background from each frame of the video. For a simple, total frame intensity algorithm, like the NRL LWVD algorithm, the lower the background the better the contrast between hot and flaming sources and therefore the better the event detection should be. This would argue for the longest wavelength LP filter available. However, as was demonstrated in our previous work [5,6], some components of typical class A fires, such as burning paper and cloth, exhibit strong atomic emission from species such as potassium and sodium in the 590 to 780 nm range. LP filters with cutoff wavelengths beyond 800 nm would filter out this emission. Therefore the choice of cutoff wavelength to use for a LP filter is an important parameter affecting the effectiveness of nightvision fire detection. Preliminary studies to address these issues were conducted during these tests. The results of the NRL algorithm for cameras 2 (small magazine) and 4 (medium magazine) were compared. The nightvision camera at position 2 was equipped with a 720 nm LP filter while the camera at position 4 was filtered with an 850 nm LP filter. Both cameras had a similar FOV of their corresponding magazines and similar tests were run in each space. While the comparison is not definitive, it should represent the relative merits of the two LP filters for flame, smoke, and nuisance detection and classification. The results of the comparison are given in Table 7 for the VS1 Test Series and in Table 8 for the CVNX Test Series. The initial results indicate that for the VS1 Test Series, the 720 nm LP filter performed better for smoldering sources than the 850 nm LP filter. For flaming sources, the filter choice did not affect the results, 100% detection. For the CVNX Test Series, the results were identical for both of the LP filters tested, 100% detection for the flaming, wood crib fires and 33% detection for the adjacent room, heptane spray fires. A caveat regarding the CVNX Test Series is that there were no nuisance sources in the test matrix and correspondingly no false alarms or any tests of nuisance rejection. Based on these results, the decrease in background image intensity provided by a longer wavelength LP filter does not improve the results for the NRL LWVD algorithm. Other factors which could affect the performance / evaluation of the LP filters are the algorithm and threshold criteria used during testing, the fine details of each source, and the measured response times. Upcoming tests will be used to optimize the selection of LP filters for the nightvision cameras [13].

LWVD Camera Comparisons

Each test magazine in the CVNX and VS1 test series had a total of four video cameras installed as described in the experimental section. In order to compare the performance of each camera location for the nightvision cameras and to then test the combined, or fused results, the final alarm status for each camera position for all of the VS1 tests was determined. Table 9 summarizes the results from the NRL algorithm for the VS1 Test Series. The results are for all forty VS1 tests analyzed by individual camera position and as system working in concert. The column labeled Camera A tabulates results corresponding to video from camera positions 1 and 3; which share similar views of both magazines. The column Camera B tabulates results corresponding to video from camera positions 2 and 4. The Either Camera column represents results from a pseudo-fused system where an alarm from either camera position, 1 and 2 for the small magazine and 3 and 4 for the medium magazine, generates an alarm for the whole system.

Table 7 – Comparison of Filter Selection on NRL LWVD Performance for the VS1 Test Series

| | Small Magazine | Medium Magazine |
|---|---|---|
| | Camera 2, LP720 | Camera 4, LP850 |
| Total Flaming Fires | 4 | 4 |
| Detected | 4 | 4 |
| Percentage Detected | 100% | 100% |
| | | |
| Total Smoldering Fires | 9 | 11 |
| Detected | 8 | 4 |
| Percentage Detected | 89% | 36% |
| | | |
| Total Flaming & Smoldering | 13 | 15 |
| Detected | 12 | 8 |
| Percentage Detected | 92% | 53% |
| | | |
| Total Nuisances | 7 | 5 |
| Nuisance Alarms | 2 | 3 |
| Percentage Incorrect | 29% | 60% |

Table 8 – Comparison of Filter Selection on NRL LWVD Performance for the CVNX Test Series

| | Small Magazine | Medium Magazine |
|---|---|---|
| | Camera 2, LP720 | Camera 4, LP850 |
| Total Flaming Fires | 5 | 5 |
| Detected | 5 | 5 |
| Percentage Detected | 100% | 100% |
| Missed | 0 | 0 |
| Percentage Missed | 0% | 0% |
| | | |
| Total Adjacent Fires | 6 | 6 |
| Detected | 2 | 2 |
| Percentage Detected | 33% | 33% |
| Missed | 4 | 4 |
| Percentage Missed | 67% | 67% |
| | | |
| Total Flaming & Adjacent Fires | 11 | 11 |
| Detected | 7 | 7 |
| Percentage Detected | 64% | 64% |
| Missed | 4 | 4 |
| Percentage Missed | 36% | 36% |

The results indicate that a simple, total frame luminosity algorithm can do reasonably well with the video provided by nightvision cameras without depending on good spatial resolution. This is a consequence of the low background characteristics of the filtered nightvision camera detection and also of using an algorithm that does not depend on any spatially resolved information. All of the flaming fires were detected by both cameras within each test space. For the smoldering fires, 60 to 70% of the sources were detected, depending on the camera. The overall success of the algorithm was between 70 and 80% for both cameras working in concert. For the nuisances sources, the number of false alarms was rather high, approaching 50%, depending on the specific camera. The last column in Table 9 contains a composite result for both cameras, where either camera going into an alarm condition trips the system as a whole. Clearly, increased sensitivity comes with enhanced nuisance susceptibility. Further work will have to be done in this area.

Table 9 – Summary of NRL LWVD Results for all VS1 Tests by Camera Position and as a System

| VS1 TEST SERIES | VS1 A | VS1 B | Either Cameras |
|---|---|---|---|
| | | | |
| Total Flaming Fires | 8 | 8 | 8 |
| Detected | 8 | 8 | 8 |
| Percentage Detected | 100% | 100% | 100% |
| Missed | 0 | 0 | 0 |
| Percentage Missed | 0% | 0% | 0% |
| | | | |
| Total Smoldering Fires | 20 | 20 | 20 |
| Detected | 14 | 12 | 18 |
| Percentage Detected | 70% | 60% | 90% |
| Missed | 6 | 8 | 2 |
| Percentage Missed | 30% | 40% | 10% |
| | | | |
| Total Flaming & Smoldering | 28 | 28 | 28 |
| Detected | 22 | 20 | 26 |
| Percentage Detected | 79% | 71% | 93% |
| Missed | 6 | 8 | 2 |
| Percentage Missed | 21% | 29% | 7% |
| | | | |
| Total Nuisances | 12 | 12 | 12 |
| Correctly Rejected Nuisance | 6 | 7 | 5 |
| Percentage Correct | 50% | 58% | 42% |
| False Alarm | 6 | 5 | 7 |
| Percentage False Alarm | 50% | 42% | 58% |

Comparison of the LWVD System to Commercial VIDS

In the initial stages of these tests, the nightvision camera video was analyzed with the LWVD algorithm and the regular cameras were analyzed in real-time by the commercial VIDS. Therefore, it was not clear whether performance differences were due primarily to the different cameras, the different algorithms, or a combination of the two. One way to address this problem was to analyze the same video sources with all available algorithm / system combinations. At the request of NRL, Fastcom Technologies post-processed the nightvision video from the entire VS1 test series (tests VS1-1 through VS1-40) using the previously discussed variant build of their SFA product. The results are listed in Table 6 in addition to the SFA analysis results of the regular video. For the SFA fire algorithm operating on video from the small magazine (Tests VS1-1 through VS1-20), the NIR and regular cameras had the same accuracy; 62.5% of the fire sources were detected correctly with 10% false alarms. In the medium magazine (Tests VS1-21 through VS1-40), 100% of the sources were correctly detected with the nightvision video while the regular video only correctly detected 12.5%. For the SFA smoke algorithm, the correctly detected events were 23.5 and 88.2% respectively for the NIR and the regular cameras in the small magazine with false alarm percentages of 50 and zero percent. In the medium magazine, the smoldering event detection percentages were 55.6 and 83.3% correct detection and 45 and zero percent false alarms for the NIR and regular cameras, respectively. The assessment by Fastcom Technologies agrees with the results of the NRL LWVD algorithm analysis and also with basic inspection of the video. Compared to regular cameras, NIR cameras are better at flaming event detection and worse for smoldering event detection.

While there is limited data available so far, as seen in Table 6, the AxonX Signifire software was able to successfully generate alarms based on reflected NIR emission from flaming sources, including sources outside the camera FOV, using video from the archive database of the nightvision cameras. Further testing and algorithm development is clearly required, particularly in the area of false alarm rejection. This work is ongoing.

The results in Table 10 are a comparison of the alarm statistics and relative response times from the nightvision camera / LWVD systems with the commercial, regular video systems which were running during the VS1 Test Series. The LWVD system performed well, with a 96% correct alarm percentage (# of correct alarms / # of non-nuisance sources) for the VS1 Test Series and a 21% false alarm rate (# of false alarms / total # of alarms). The LWVD appears to be more sensitive to flaming and smoldering sources, but suffers from correspondingly higher false alarm sensitivity. Work is underway at NRL to increase the nuisance discrimination while maintaining the detection sensitivity. For sources where more than one system went into alarm, the LWVD system reached an alarm condition faster than the commercial systems at least 50% of the time for the SFA and the Signifire systems and 100% of the time for the VSD-8 system. The VSD-8 only alarmed on three tests, so the statistical significance of that percentage is unclear. Table 11 presents the summary results for the nightvision / LWVD and regular / SFA systems from the CVNX Test Series. The LWVD detected 18 of the 22 total source fires while the SFA detected 11, or 82 and 50% detection, respectively. As stated above, there were no nuisance sources in the CVNX Test Matrix, so the nuisance rejection was not measured for the CVNX Test Series.

For tests where both systems went into alarm, the LWVD alarmed faster for 88% of the sources. Comparison of the system response times for tests with mutual alarms indicate that the LWVD system, as configured, responded on average 2 to 3 times faster than the other VID systems for flaming fires, and approximately 2 times slower for smoldering events based on the VS1 results. Caution is advised in drawing conclusions from these results, in particular for the smoldering events where the LWVD and regular cameras are not necessarily detecting the same smoke events. For example, for the smoldering cables tests, the LWVD system could be detecting the NIR emission from the hot cartridge heater in addition to the smoke plume while the regular VIDS are only detecting the smoke. For the potassium chlorate / lactose sources, the LWVD system may detect the atomic potassium and NIR emissions from the flame as well as the smoke cloud detected by the regular VIDS. One should also note that the LWVDs nuisance rejection algorithm is very immature in comparison to the regular VIDS and the result of any improvements would most likely lead to slower response times.

Table 10 – Summary of NRL LWVD for the VS1 Test Series

| | | **Regular Video** | | |
|---|---|---|---|---|
| | **LWVD** | **SFA** | **VSD-8** | **SigniFire** |
| Total Tests | 40 | 40 | 40 | 40 |
| Total Alarms | 34 | 23 | 3 | 26 |
| Correct Alarms | 27 | 20 | 3 | 24 |
| Percentage | 96% | 71% | 11% | 86% |
| False Alarm | 7 | 3 | 0 | 2 |
| Percentage | 21% | 13% | 0% | 8% |
| | | | | |
| Mutual Alarms | | 23 | 3 | 26 |
| LWVD Faster? | | 13 | 3 | 14 |
| Percentage | | 57% | 100% | 54% |

Table 11 – Summary of NRL LWVD for the CVNX Test Series

| | | | |
|---|---|---|---|
| Total Tests | 22 | Total Tests | 24 |
| LWVD ALARMS | 18 | SFA ALARMS | 11 |
| Correct Alarms | 18 | Correct Alarms | 11 |
| Percentage Correct Alarm | 82% | Percentage Correct Alarm | 50% |
| | | | |
| | | # of Mutual Alarms | 8 |
| | | LWVD Faster? | 7 |
| | | Percentage | 88% |

## HOT OBJECT DETECTION

Hot objects, such as bulkheads heated by fires in adjacent spaces, can be detected with nightvision cameras, which offer an attractive alternative to significantly more expensive Mid-InfraRed (MIR) or thermal imaging cameras. Tests CVNX-31 through -36 and CVNX-44 through -49 were designed to simulate fires in spaces adjacent to ordinance storage magazines. The adjacent fire sources used were heptane spray fires set up outside the compartment facing the forward bulkhead of each test magazine and configured to yield peak (relative to time), spatially-averaged bulkhead temperatures of 155 to 360 °C [8] as detailed in Table 3. A network of calibrated K-type thermocouples (TC) was arranged on the portion of the forward bulkhead to be heated by the heptane spray fire [2]. A frequent question regarding the nightvision cameras that are the subject of this report is the temperature range of hot objects that can be detected. As the ship's bulkhead is between the camera and the source, the luminosity detected by the nightvision cameras is presumably from blackbody radiation from the heated bulkhead. The heptane spray fires present an excellent opportunity to gather data under real test conditions. For test CVNX-49, the nightvision camera in position 4 had a clear, relatively unobstructed view of the heated bulkhead. The LWVD algorithm was used to analyze the nightvision video from this test. The luminosity time series are calculated for three discrete areas of each video frame and normalized for total number of pixels in each region. The results are shown in Figure 9. The areas corresponding to the time series are shown in Figure 10, a still image from the CVNX-49 test, camera location 4, approximately 20 minutes after ignition. The first region is the source region, as depicted by the red box in the center of Figure 10. The second region, shown in green in the upper right-hand corner of Figure 10, is a well-illuminated portion of the image as a reference, and the third region, outlined in blue in the lower left-hand corner of Figure 10, is a dark reference. The illuminated background area was analyzed to monitor the camera output for changes in image gain. To remove any residual background luminosity from the time series, the pre-ignition, dark background luminosity level was subtracted from each time series.

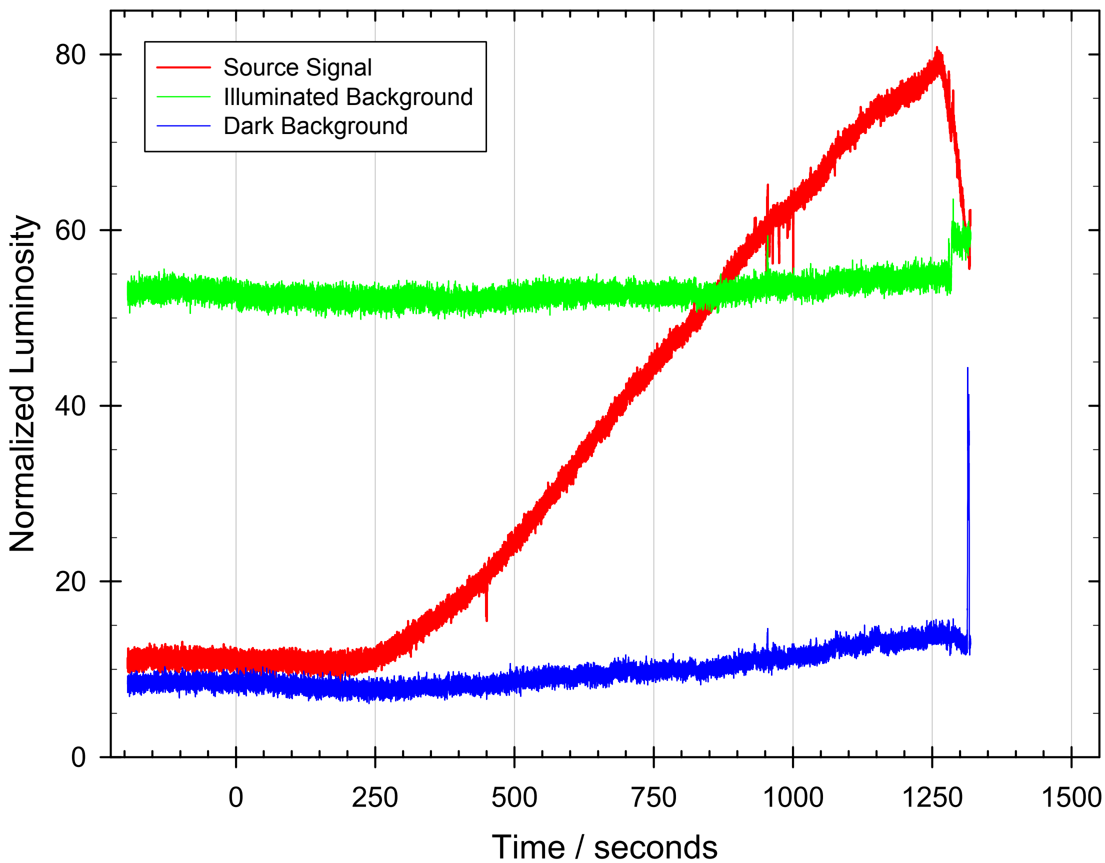

Fig. 9 – LWVD Luminosity time profiles for test CVNX-49, camera position 4

Using the TC temperature data recorded during test CVNX-49 [8, 15], the temperature of the bulkhead can be compared to the total luminosity, as shown in Figure 11. The thermocouple time series is shown for the BH 3-24-2 3 ft. TC, which measured the highest peak temperature.

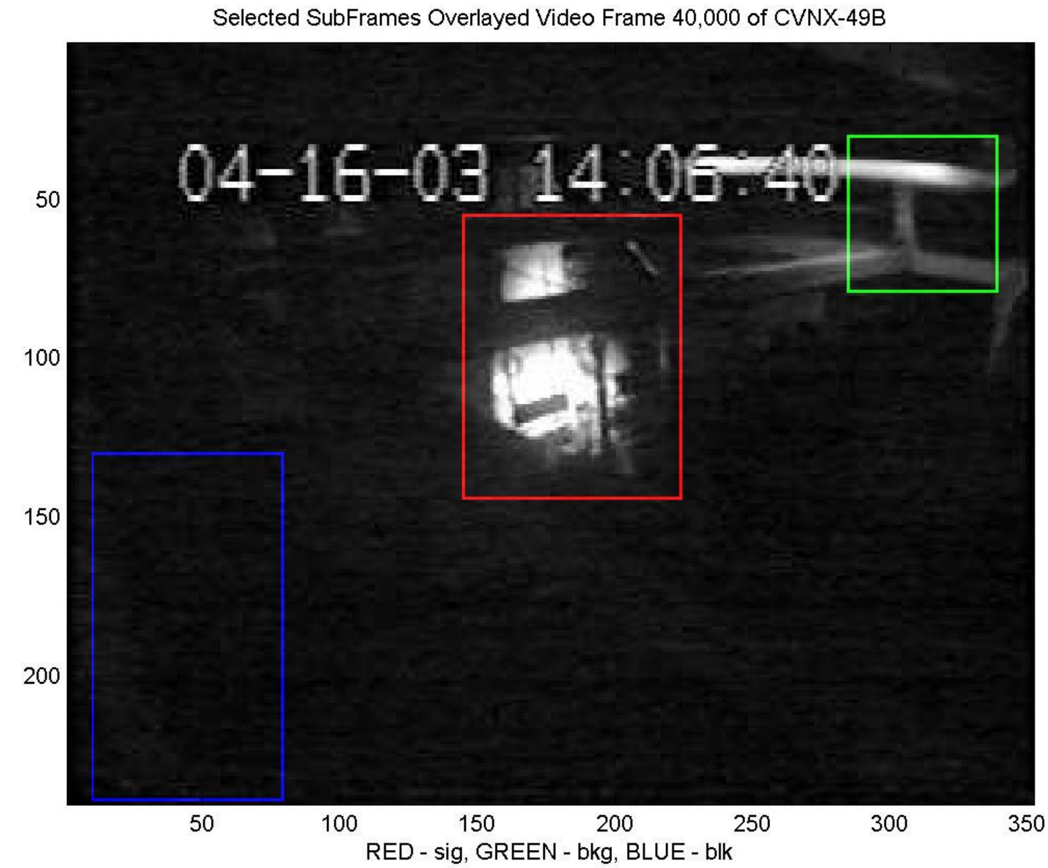


Fig. 10 – Subframes used for LWVD analysis of test CVNX-49, camera position 4

In the case of test CVNX-49, the total luminosity for the source region begins to rise above the baseline value approximately 250 seconds after ignition. The total luminosity increases nearly linearly until reaching a peak value approximately 1250 seconds after ignition and then drops rapidly. The temperature profile increases rapidly towards a peak value near 600 °C at approximately 1400 seconds and then cools after the end of the test. As can be seen in Figure 11, the luminosity values increases a factor of 17 for the bulkhead temperature rising from 370 °C to 565 °C. Table 12 gives the calculated source luminosities and luminosity ratios for the last three times depicted in Figure 7: 240, 740, 1245 seconds after ignition as well as the thermocouple temperature in °C. The pink vertical lines in Figure 11 denote the times of the three post-ignition images in Figure 7. The luminosity ratios are provided to emphasize the change over time of the luminosity for the source region in comparison to the change in temperature (ΔT).

It should be possible to rationalize the detected luminosity in terms of the temperature dependence of blackbody emission. Luminosity values above the baseline value are detected after approximately 280 seconds. This threshold luminosity detection coincides with a TC temperature of 370°C. The absolute luminosity measurement in the test is subject to several parameters, such as the source-camera separation, whether or not the bulkhead is truly a blackbody emitter, the wavelength dependence of the CCD array quantum efficiency, the CCD exposure time, and CCD and digitizer pixel saturation. The emitting area increases as the test proceeds, unless this is accounted for the calculation should underestimate what is observed. Constraints on the measurements that are potential sources for the deviation of the observed luminosity from the calculated luminosity include the following. First, the thermocouple represents a direct-contact, point measurement of local temperature while the total luminosity measurement is only for a portion of the video frame, which may include other sources of luminosity. Second, the physical geometry relating the TC and the FOV of the LWVD camera is not exactly known. The thermocouple location may not have been exactly collocated with the peak luminosity in the video frame that is presumably the source location.

Table 12 – LWVD Luminosity and TC Temperature Results for CVNX-49, Camera 4

| **Time** (seconds) | **Luminosity** (norm., baseline) | **Ratio** | **Temp.** deg °C | **ΔT** deg °C | **Subpanel of Figure 7** |
|---|---|---|---|---|---|
| 280 | 4.13 | 1.00 | 370 | - | b) |
| 740 | 35.54 | 8.60 | 540 | 170 | c) |
| 1245 | 68.81 | 16.6 | 565 | 25 | d) |

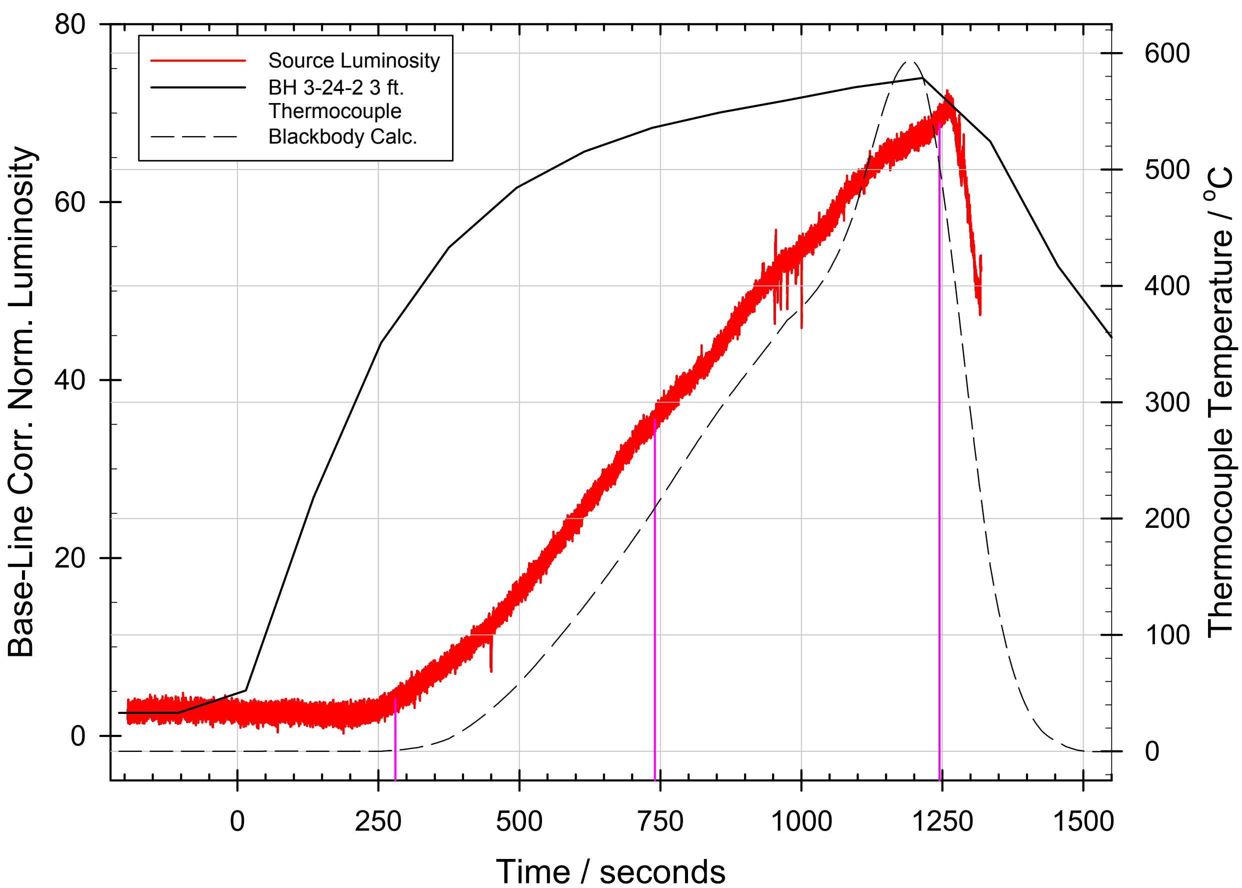


Fig. 11 – Thermocouple Temperature and LWVD Luminosity time profiles for test CVNX-49, camera position 4

A useful resource for the thermal response of a CCD camera is reported by Sentenanc et al. [16], who used a CCD camera similar to the ones tested to measure the temperature of hot objects for remote monitoring in aircraft cargo bay applications. They quote a minimum detectable temperature in the range 350-400° C, which is consistent with our results. In order to verify and calibrate the CCD response to temperature and to establish the minimum temperature for CCD detection, luminosity measurements were made of a blackbody emitter as a function of temperature in the laboratory. Both types of cameras used in the CVNX and VS1 test series were tested using the LWVD system to provide quantitative values for the camera response.

The emitted intensity, $I(T,\lambda)$ in mW cm$^{-2}$ μm$^{-1}$, for a blackbody radiator as a function of temperature (K) and wavelength (λ in microns) is given by the equation [17]:

$$I(T,\lambda) = \frac{c_1}{\lambda^5\left(\exp\left(\frac{c_2}{T\lambda}\right)-1\right)} \qquad (1)$$

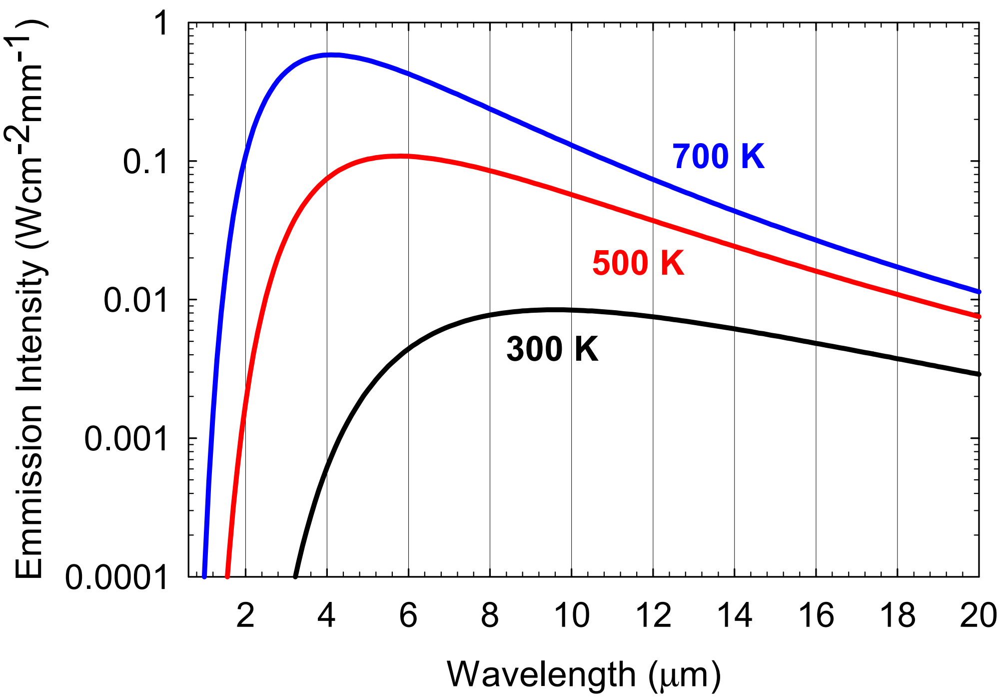


Fig. 12 – Calculated blackbody curves for 300 K, 500 K, and 700 K

where the effective constants are $c_1=3.7405\times10^4$ and $c_2=1.4388\times10^4$. The Wien displacement law [18] for blackbody radiation is also a useful expression; it relates the constant given by the product of the wavelength of the emission intensity maximum and the temperature.[4]

$$\lambda_{max} \times T = 2980 \text{ microns-K} \qquad (2)$$

[4] Note that in the blackbody equation and in the plots in Figure 13, temperature is expressed in Kelvin (K). All other temperature references in this report are expressed in Centigrade (°C).

Calculated emission profiles for three temperatures are shown in Figure 12. For example, the maximum emission at 500 K is at 6 microns. As the temperature increases, the absolute maximum intensity increases and the wavelength at which the maximum occurs shifts to shorter wavelengths. The CCD camera response as a function of temperature is calculated by integrating the emission over the spectral range detected by the nightvision cameras at a given temperature:

$$I(T) = \int_{750}^{1000} I(T,\lambda)d\lambda \quad (3)$$

where *I(T)* is the predicted emission intensity for a blackbody radiator, integrated over the detection window of the nightvision cameras, 750 to 1000 nm.

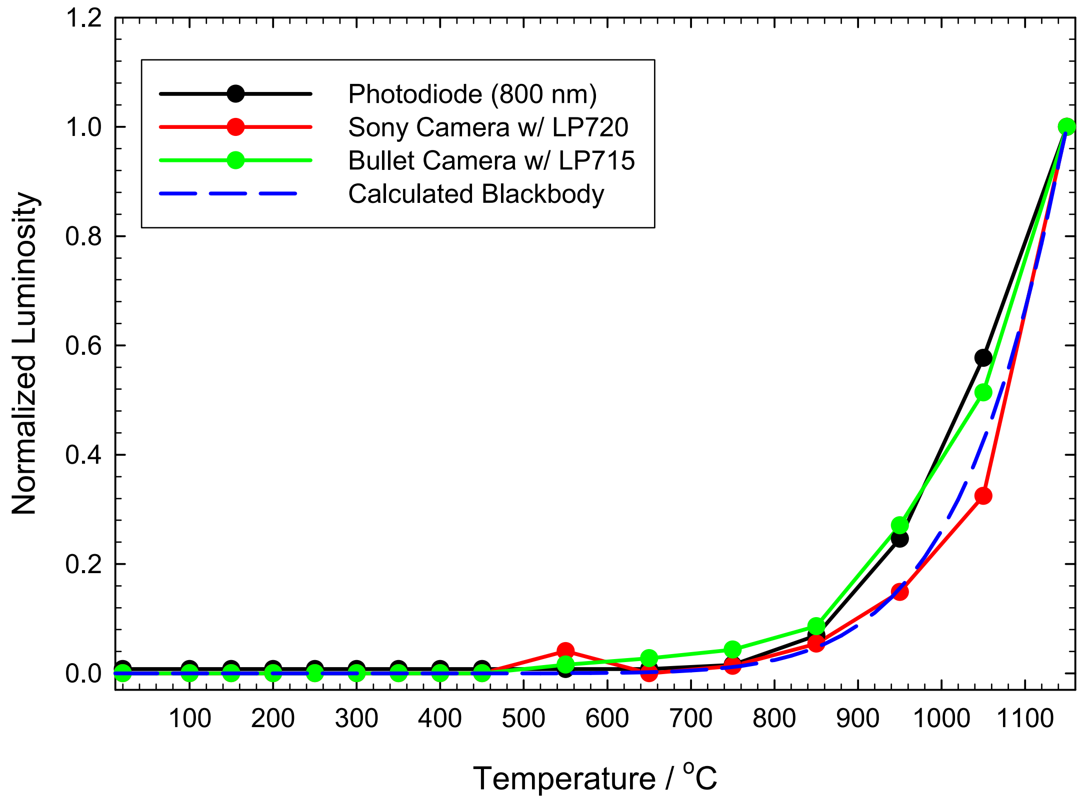


Fig. 13 – LWVD Luminosity and PD time profiles for a blackbody source

The basic idea behind the laboratory measurements was to expose the nightvision cameras to a blackbody source, heated to a known temperature, and calculate the luminosity response for each camera as a function of source temperature. The blackbody source provides a thermally and spatially well-defined source for calibrating the LWVD system response. The cameras were placed approximately 3.1 m from the source such that both cameras had the same FOV including the source. A calibrated blackbody radiator (Infrared Industries, Inc., Model 464) was used to measure the luminosity response of both LWVD cameras (the CSi-SPECO (Bullet Camera w/ LP715 on Figure 13) and the Sony version (Sony Camera w/ LP720)) as a function of source temperature. The output of a filtered silicon photodiode (PD, 800 nm center frequency, 10 nm FWHM) was also measured for comparison to the results from the SBVS Testbed [6]. The photodiode was positioned approximately 2.1 m from the source and the output was measured with a DVM.

The normalized results are shown in Figure 13. The results were normalized such that the background luminosities are set to zero and the peak value is set to unity. The normalized, calculated blackbody emission is also shown. There is very good agreement between the observed and calculated relative emission intensities. Also, the blackbody source results, calculated using Equation 3, indicate that source temperatures on the order of 400 °C are required to detect the source with the LWVD system. This result can be visually extracted from Figure 11. The total luminosity for CVN21-49, camera position 4 rises measurably above the background value around 250 – 300 seconds after ignition. At this time, the recorded TC temperature is approximately 400 °C. The results of a similar calculation are plotted in Figure 11 as a dashed line, showing the predicted blackbody emission intensity corresponding to the measured TC data. There is good agreement between the predicted luminosity and the luminosity measured by the LWVD system.

## CONCLUSIONS

Nightvision cameras, as defined in this report and in our previous work, offer an attractive and cost-effective augmentation to the standard implementation of VIDS technologies as seen in currently available commercial systems. The NRL LWVD system emphasizes detection of fire and hot objects both within the camera FOV and outside the camera FOV. The NIR radiation from flaming and hot objects is sufficiently intense in the observation band of the nightvision cameras (700 – 1000 nm) to quickly detect fires and hot objects such as overheated cables and ship bulkheads heated by a fire in an adjacent compartment. The commercial VIDS are not sensitive in this spectral region and must rely on smoke generation to detect fires, which are smoldering or are outside the camera FOV. Smoke is not sufficiently hot to generate NIR radiation therefore any NIR-based VIDS would have to rely on ambient room illumination to visualize smoke. Since the ambient illumination is typically suppressed or removed by the LP filters used in the nightvision cameras, smoke is not easily detected by the LWVD system. The fusion of standard VIDS, which have fairly robust smoke detection, with the enhanced flame and heat detection of the that are heated to greater than 400 °C are detectible by the LWVD system. The LWVD system already shows promise as an inexpensive pseudo-thermal imaging system for remote monitoring of surface temperatures. As part of the NRL LWVD system, a simple total luminosity-based MV algorithm has been developed to support the nightvision camera development. The algorithm was used to analyze test videos recorded during the VS1 and CVNX test series in April, 2003. The LWVD system as a whole will be further tested in upcoming tests. Both spatial and time-series analysis will be incorporated into an enhanced version of the LWVD algorithm in a parallel effort to the planned testing.

## ACKNOWLEDGEMENTS

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**APPENDIX A**

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**NOVA-2027-TR-0001**

# CAPTURE AND ARCHIVAL STORAGE OF LIVE VIDEO STREAMS FOR THE VOLUME SENSOR VIDEO-BASED EVENT DETECTION SYSTEMS

Special Technical Report
submitted in partial fulfillment of
the requirements of NRL Contract No.
N00173-02-C-2010

"Research and Development In The Areas of Chemical
Dynamics and Diagnostics"

Dr. Daniel A. Steinhurst

June 16, 2003

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# CAPTURE AND ARCHIVAL OF LIVE VIDEO STREAMS FOR THE VOLUME SENSOR VIDEO-BASED EVENT DETECTION SYSTEMS

## 1.0 Introduction

The Volume Sensor (VS) system is an important component of the Advanced Damage Control program for Future Naval Capabilities. The VS system is being designed to assess damage conditions within a ship space without relying on point source measurements and / or continuous crew monitoring. Several technologies were identified that have potential for meeting the objectives of the VS system criteria [1]. During FY02, two video-based detection technologies were evaluated and adapted for improved situational awareness and damaged control assessment onboard US Navy ships with a particular emphasis on smoke and fire detection [2, 3]. Further testing was conducted in FY03 onboard the ex-USS *SHADWELL*, the Naval Research Laboratory full-scale fire research facility [4], as described in the test plans for the Volume Sensor 1 (VS1) and CVNX Fire Threat to Ordnance (CVNX) test series [5].

Currently all cameras used during test series as inputs for the video-based event detection systems and any other additional cameras used for test observation are recorded onto video cassettes for archival purposes as indicated in References 2 and 5. Videocassettes as a storage media are bulky and require access to a VCR and a video monitor for playback of a particular video clip at a later time.

In the FY03 effort of the VS program, new video-based event detection systems are being identified and developed. These new systems require validation and testing on the same data as the original two systems for comparison. All of the video-based systems are computer-based, which allows them to be developed and tested using previously recorded video from past test series. An archive of such video must be archived in a compact, digital format to be usable. As an example of the uses of such an archive, a standard suite of test videos could be made available new systems / vendors for testing purposes and system validation.

The concept of a fire video archive was conceived based on these two points. This archive is to contain compact format, digitized videos of all available test data in the most general, least lossy format available. As an example of the generality sought, the two video-based event detection systems evaluated during FY02 were designed to accept analog video signals as their input sources. The inputs come as either live images from a video camera or as pre-recorded video from a VCR or other analog video recorders at 30 FPS. The video is captured or digitized by the system computer at 1-2 FPS, depending on the system. Once captured, the digitized image is analyzed by the systems and a still image may be recorded for documentation purposes when an alarm or pre-alarm condition is observed. None of the unanalyzed images are saved in any manner by either of the systems. Archiving the video at 2 FPS would be sufficient for testing current technologies systems, but systems identified in the future may be able to process images at a higher rate and the archive must be designed with these types of issues in mind. The results of the VS1 test series for the video-based systems include a new 12 FPS system that may have outperformed the commercial systems [3].

This report will document the specification development for the archive and the equipment necessary to implement a system for the direct real-time capture and archiving of future test series without the need for intermediate videocassette archiving.

## 2.0 Digitized Video Specification

The current archiving protocol is multi-stepped. The analog output of the camera is sent to a video timer (FOR-A Model VTG-22 or equivalent) and then split by a powered amplifier. The divided signal is then sent to a VCR for archiving and to the video-based system for analysis. The videocassette archives are then digitized using the Dazzle Hollywood DV Bridge unit and a VCR as described in Section 3. To do a comparable job of archiving to the VCR, the system must be able to accept video meeting the following specification:

- 352 x 240 pixel resolution[1] NTSC compatible inputs
- 30 FPS video[2]
- A minimum of eight hours of continuous capture

## 3.0 Real-Time Video Capture System (RTVCS) Specification

The specification for the video input presents some interesting challenges from a technical standpoint. First, the AVI digital video format was selected based on its general portability between computers, and operating systems. A poll of the available event detection system manufacturers indicated that their products could interface with the AVI format as well. The MPEG formats (-1, -2, and –4 / Divx) were rejected as less general and using codecs, or compression / decompression software, which are more lossy (i.e., more information is discarded in the compression step which can not be recovered during decompression).

The capture device chosen can have a dramatic effect on the final file size for captured video based on the available capture configurations and supported file formats and codecs. Three video capture devices were tested along with the included software and codecs on a P4-1.7 GHz PC running the Windows 2000 operating system and the NTFS 5 file system[3]. The three systems tested spanned a range of price and connection speed / bandwidth availability:

- Belkin USB VideoBus II, USB v.1 interface, VideoWave III SE software, $99 USD MSRP
- Dazzle Hollywood DV Bridge, FireWire (IEEE 1394, i-link DV interface), VideoWave III SE software, $250 USD MSRP
- ATI ALL-IN-WONDER 9700 PRO, an AGP video card, and ATI's MultiMedia Center v.8.1 software, $450 USD MSRP

The Belkin unit, utilizing a USB v.1 interface was not capable of real-time (30 FPS) capture of video at 352 x 240 without losing a significant number of frames. While inexpensive, this unit was not acceptable. The Hollywood DV Bridge is sold as a media converter, accepting both digital and analog inputs and outputs. Media conversion with the DV Bridge such as analog video input to digitized video

---

[1] 352 x 240 pixel resolution is the resolution of less-expensive CCD cameras such as the ones used in the VS program. The commercial video-based systems do not require higher resolution cameras.

[2] One should note that the NTSC transmission standard is 29.97 FPS, but many video devices including computers run at 30 FPS.

[3] The FAT32 filesystem can not handle files sizes above 2 GB. Several capture device vendors and the Microsoft KnowledgeBase on-line database indicates this problem.

output to a PC (A to D conversion) or digitized video output from a PC to a digital camcorder (digital copying) is simple and convenient. One caveat is that the DV Bridge is inherently a DV-format device due to the design of the FireWire/DV interface, forcing all digital information passed though it to comply with this standard. The DV format is AVI based but at a natural resolution of 740 x 560 pixels, without compression, and with mandatory audio tracks. Any video captured in the DV format produces extremely large video files.

As an example, 194 sec of video captured via the DV Bridge produces an AVI file 643 MB in size, or 3.3 MB/sec. An eight-hour recording session would produce 95 GB/day of video. Assuming that the capture was broken into files which would fit onto a writable DVD medium, a well-appointed computer (see final specification below) capable of holding 2 day's of video would require 42 4.7 GB DVDs to be written to archive the video which is prohibitive considering the write time on a DVD is 30 to 45 minutes each, or approximately 11 hours of DVD writing per full day of video capture.

One could compress the video after capture but prior to archiving. Tests were run with several codecs and the best codec, which is included with the basic Windows suite of programs, was the Intel Indeo v.5.1 codec. The Indeo codec was able to compress the DV-format files into AVI files at 352 x 240 pixel resolution with audio at a rate of 50 MB/minute or 0.83 MB/sec, a factor of four compression. The Indeo codec is not particularly fast, running at approximately one third of real time. Video processing in this manner would take four times the running time of the video, once to capture and three times longer to digitize, all prior to writing the DVD.

The final system tested was to replace the PCs standard video card with the ATI capture board. The ALL-IN-WONDER (AIW) card's documentation claims the ability to capture MPEG-2 format video at a resolution up to $720 \times 480$ pixels at 30 FPS. ATI technical support indicated that this would also be true for AVI format capture [6]. Initial testing found that the ATI software was capable of capturing video into AVI files at either 30 FPS uncompressed or 15 FPS compressed with the generally available codecs. Further research located a commercial codec from LEADTools, Inc. (http://www.leadtools.com), the LEAD MCMP/MJPEG codec, which in combination with the ATI card and the current version of the MCC software is able to capture video at 30 FPS in a compressed AVI file format. The observed compression factor is 6 to 10 times. This commercial codec currently costs $29/seat. The cost issue will be addressed in more detail in Section 4.

A final test of the ATI / LEADTools combination produces uncompressed AVI files of ~1 GB in length for approximately 3 minutes of video and stereo audio, or 5.5 MB/sec. The same video source captured and stored as a compressed AVI file produced a file approximately 100 MB in length, for a storage rate of 550 KB/sec. Compression of 6 to 10 times appears to be typical as compared to uncompressed AVI for a variety of video sources with and without audio tracks.

The final minimum recommended hardware configuration or specification is therefore:

A Pentium 4-class PC (including monitor, keyboard, mouse)

- 2.4 GHz minimum processor speed
- 533 MHz FSB, 512 KB L2 cache
- 512 MB PC1066 RDRAM
- 4x/8x AGP for next item
- ATI ALL-IN-WONDER 9700 PRO video capture card
- 200 GB UltraATA/100 HDD (7200 RPM, 8 MB cache)
- Microsoft Windows 2000 Professional

- DVD-RW disk writer and software[4]

The current MSRP of such a system is $2700 USD. If the capture system is to be used in a harsh environment, a hardened rack mount enclosure for the computer and industrial grade monitors and input devices should be considered.

Setup and Operation Instructions for the prototype RTVCS are included in Section 8.

## 4.0 System Limitations

While the final system appears to function extremely well, there are a few caveats that should be acknowledged. The first issue is that the codec used is not a freely distributed piece of software and even individuals who only wish to access the archive will need to purchase a copy of the codec. While a reliance on LEADTools to supply, maintain, and support their codec in the future is implicit in building this system, it seems no more problematic than assuming that Microsoft and ATI will maintain and support the operating system and capture card, respectively. In other words, support for any one component of the system should not affect the overall stability and maintainability of the entire system over time.

As mentioned above, the capture of the audio tracks will affect the size of resultant AVI files and the overall compression factor. Of the current set of cameras used in the VS program, only one type is capable of providing audio tracks, the Sony camcorders (Models DCR-TRV27 and DCR-PC101). The open audio line-in terminals can cause a noise-filled audio track to be generated in the AVI files for video sources that do not also provide audio. Ideally, one would not capture the audio tracks, but the software collection currently used does not support this option. Proper termination of the audio inputs should be able to reduce the noise level if the audio tracks must continue to be captured. The audio track can be removed after the fact if necessary, for demonstrations as an example. The video-based systems do not currently process the audio if present, so this is only an annoyance for the data analyst reviewing the video at this time.

The final step of the archiving process is to transfer the AVI files to the blank DVD media. The DVDs must be generated after the fact due to bandwidth limitations of the burner hardware and the PCs at the present time. To generate a DVD, even PCs of the class described in the last section must not be running any other processes during the generation step or the DVD may be corrupted. Presumably the hardware will improve in the near term such that the DVDs could be generated "on-the-fly" without the intermediate storage step.

The last system limitation is scalability. The system proposed for meeting the specification given in Section 3 does perform as required. However, it does so at the cost of one high-end PC with an AGP per camera. Therefore the system is not scalable in either physical size or cost for test spaces larger than a few compartments or especially for an entire ship (with as many as 5000 cameras). A potential candidate improvement has been identified and may be evaluated in the future. The Matrox Morphis line of imaging cards is capable of capturing 2 video channels simultaneously with hardware JPEG2000 image compression. JPEG2000 compression is a similar technique to the one used by the LEADTools codec. These cards are standard PCI cards and a current PC should be capable of operating three of these cards

[4] Our current specification is for DVD-R(W) for compatibility. An isolated installation could use the DVD+R(W) standard without any loss of functionality.

simultaneously within the bandwidth of the PCI bus (currently 66 MHz clock speeds). This would allow the use of small form factor industrial PCs to capture and archive six cameras at once. The Morphis card costs approximately $900 USD each for a total system cost of $5000 USD or $820 USD per camera as compared to $2700 per camera for the ATI based system. Clearly, a card capable of performing at this level would present an option for the next step in scaling up the capture process.

## 5.0 Conclusions

To facilitate the testing and development of VS video-based event detection systems, a specification for a computer-based system to capture and archive test series video in real-time was developed and a prototype tested. A video file format sufficiently compressed to be practically stored was specified. Three separate systems were evaluated for performance towards these specifications and one system was found to be acceptable.

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## 7.0 Abbreviations Used in Text

| | |
|---|---|
| AGP | Accelerated Graphics Port |
| AVI | Audio Video Interleaved |
| CODEC | Compression / Decompression software |
| CVNX | Carrier Vehicle, Nuclear Experimental; the next generation aircraft carrier program. Also referred to as CVN21. |
| DivX | A extremely compact, if lossy, digital video and audio format. Also known as MPEG-4. |
| DV | A digital video and audio format |
| DVD | Physical media format, sometimes referred to as Digital Versatile Disc. |
| DVD+R(W) | (re)writable digital versatile disc media compliant with the DVD+R/RW Alliance standard. |
| DVD-R(W) | (re)writable digital versatile disc media compliant with the DVD R/RW Forum standard. |
| FAT32 | An older Microsoft-developed file system for computer disks, removable and fixed |
| FireWire | A serial communications protocol, also known as Sony i.Link, IEEE 1394 |
| FPS | Frames Per Second |
| FSB | Front-Side Bus |
| HDD | Hard Disk Drive |
| JPEG | Joint Photographic Experts Group. Also a standard for still digital images. |
| JPEG2000 | Second generation of the JPEG standard for still digital images |
| L2 | Level 2 |
| MJPEG | Motion JPEG standard for digital video |
| MPEG | Moving Picture Experts Group, standards for digital video and digital audio compression |
| MSRP | Manufacturer Suggested Retail Price |
| NTFS | The current Microsoft-developed file system for fixed computer disks |
| NTSC | Abbreviation for National Television Standards Committee standard. North America and others uses this standard (525-line interlaced raster-scanned video) for the generation, transmission, and reception of television signals. Picture information is transmitted in vestigial-sideband AM and sound information is transmitted in FM [7]. |
| P4 | Intel Pentium 4 |
| PCI | Peripheral Component Interconnect, an interconnection system between a microprocessor and attached devices |
| RDRAM | RAMBUS DRAM, a high speed computer memory type |
| USB | Universal Serial Bus |
| USD | United States Dollars |
| VCR | Video Cassette Recorder |
| VS | Volume Sensor, A component of the Advanced Damage Control program |
| VS1 | Volume Sensor Test Series 1, conducted onboard the ex-USS SHADWELL, April, 2003 |

## 8.0 RTVCS V0.9 SETUP AND OPERATION INSTRUCTIONS

1. System Setup

Setup is same as for a typical PC. Most every connection is shape and or color coded. Connect video source to video connector (yellow RCA jack) on purple A/V In box.

Notes: Purple A/V In box connects to connector on video card.
Black A/V Out cable connects to connector on video card and 1/8" dia. phono connector connects to blue connector on sound card (Line In).

2. System Login

For **<u>all</u>** systems, username: Video
password: Video1

3. Program Startup

Select TV on the ATI Multimedia Center toolbar (right-hand part of screen) or on the Start/All Programs/ATI Multimedia Center Menu. Program should open w/ the composite (RCA jack) source in window (i.e. if camera is on, picture should be there).

To capture video, select "Start Recording" Button (camera symbol), or press <Ctrl-R>. To stop capturing video, select "Stop Recording" Button (in new window) or press <Ctrl-R>. A dialog box will open which will prompt the user for the filename and location. Files are encoded using the LEAD MCMP/MJPEG codec.

4. Software Configuration

Open the Setup dialog box by selecting the Setup icon (a check box) or pressing <Ctrl-S>. The following configuration settings should be verified prior to video capture. On the Video tab, verify that the connector is set to composite. On the Personal Video Recorder (PVR) tab, check that the preset selected is the "Fire FNC Test 1." The One Touch Record button on the PVR tab opens a dialog box where the capture file default location and the file name style can be set.

5. Copying AVI files to DVD for Archiving

The VOB InstantCD/DVD software package has been installed to operate the DVD burner installed in the computer. If necessary, refer to the available documentation for the software for usage instructions. The DVD burners use 4.7 GB **<u>DVD-R(W)</u>** media.

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